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Instrumented experiments aboard the frigate "WOLF". Wolf II: Measurement results of the 15 kg TNT experiment in the crew aft sleeping compartment

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Summary

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).
In this report the recordings of an instrumented experiment in the crew aft sleeping compartment are presented. During this experiment, a non-fragmenting charge of 15 kg TNT was initiated.

Samenvatting

In het kader van het onderzoek naar de kwetsbaarheid van schepen zijn in 1989 een aantal experimenten uitgevoerd op het fregat "WOLF" van de Roofdierklasse (PCE 1604 class) (Wolf, Fase II).
In dit rapport worden de meetresultaten gepresenteerd van een geïnstrumenteerde beproeving van het manschappen slaapcompartiment op het achterschip. Tijdens dit experiment werd een kale, 15 kg TNT lading tot ontploffing gebracht.

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CONTENTS

1 INTRODUCTION

In order to obtain quantitative as well as qualitative information on the effects of internal and external explosions on a frigate, a number of (instrumented) experiments were performed on the frigates "FRET" and "WOLF" (Figure 1). These are Roofdier class frigates, the former United States Navy PCE 1604 class, which were decommissioned by the Royal Netherlands Navy. A general overview of the Roofdier trials is given in Table 1.

Table 1 A general overview of the Roofdier trials

Fret I	June/September 1987	(v.d. Kasteele and Verhagen, 1989)
Wolf I	October/ November 1988	(v.d. Kasteele and Zwaneveld, 1989)
Wolf II	September/October 1989	(Verhagen and v.d. Kasteele, 1992)

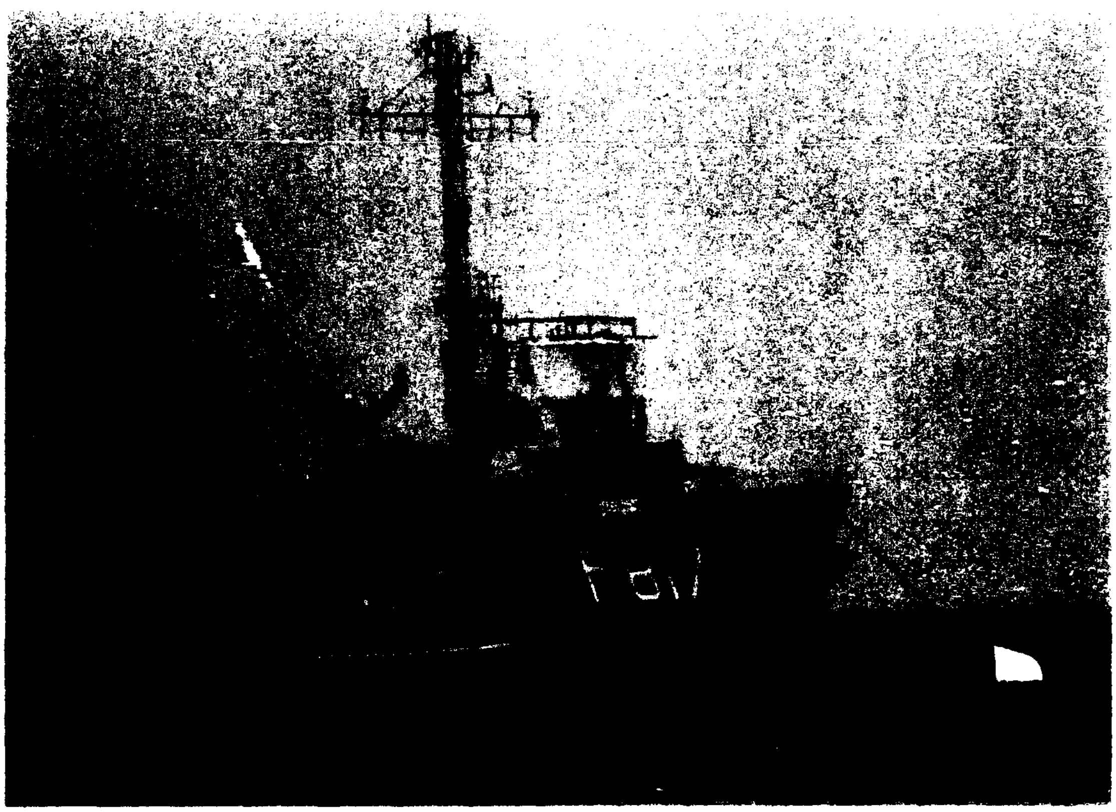


Figure 1 Wolf frigate

Pressure, strain, acceleration etc. were recorded during the Wolf Phase II bare charge experiments. These experiments were performed in the crew aft as well as the crew forward sleeping compartment. In the crew aft sleeping compartment, the 2, 5.5 and 15 kg TNT bare charge experiments were all performed on one day. The volume of this compartment was ±77 m^3, thus realizing a "charge density" of ±0.026, ±0.072 and ±0.20 kg/m^3.
The 3 and 12 kg TNT bare charge experiments were performed in the crew forward sleeping compartment on one day. The volume of this compartment was ±105 m^3, thus resulting in a "charge density" of ±0.029 and ±0.11 kg/m^3.
During these Phase II experiments special attention was paid to the blast resistance of the watertight doors (i.e. the 2, 3 and 5.5 kg TNT experiments), the resistance of the structure (the 12 kg TNT experiment) and the rupture of structural elements (the 15 kg TNT experiment).

The recordings of the instrumented Wolf Phase II experiments presented conform to the previous reports dealing with the recordings of the Fret and Wolf Phase I experiments. Each report can be regarded as an independent report. It goes without saying that it is not within the scope of these reports to discuss the recordings in detail or even to compare the recordings with theoretical predictions. That will be an integral part of the reports presented by van Erkel (1992).
Nevertheless, some additional information is given concerning the reliability of the presented recordings.

Due to the increased knowledge and experience gained from the Fret and Wolf Phase I trials, modified mounting and protection techniques were used during the Wolf Phase II trial. It is for this reason that a separate report deals with the general background information as well as the mounting and protection methods used. For the sake of completeness, a description is also given of the registration equipment and the signal analysis system used.

This report deals with the bare 15 kg TNT experiment in the crew aft sleeping compartment.

Some general remarks on the experiment are given in Chapter 2, as well as some specific information of the charge used. In the following chapters, the recordings are presented.
On the presented signals, offset elimination was carried out. The time axis used was related to the moment of ignition of the charge (t=0).

The 2 and 5.5 kg TNT experiments were performed earlier that day in the same compartment. It is for this reason that there was no time available between the experiments for the technicians to repair

the damaged transducers. As a consequence, some of the signals were omitted from this report. The damage to the frigate was not repaired either, only the ruptured upper deck was provisionally repaired.
Some abbreviations often used are BHD (Bulkhead), SB (Starboard), PS (Portside) and CL (Centre line frigate).

2 DESCRIPTION OF THE EXPERIMENT

2.1 Objective of the experiments

One of the objectives of the ROOFDIER trials is the validation of the computer code "DAMINEX" as developed by the Weapon Effectiveness Department of the TNO - Prins Maurits Laboratory.
The DAMINEX code determines the structural damage to a frigate due to internal blast. A number of theoretical assumptions were made during the development of this code, which however may have a large influence on the final simulation results.
In general, the damage caused by the experiments can be registered visually. It is for this reason that a lack of quantitative information is still apparent. The specific goal of the ROOFDIER experiments is to gain more quantitative as well as qualitative information by performing well-documented experiments. This information will be used to validate (or even modify) the DAMINEX code.

2.2 Experimental set-up

Two crew sleeping compartments were chosen by the Weapon Effectiveness Department for the instrumented experiments: the crew forward sleeping compartment and the crew aft sleeping compartment. These two compartments correspond with the crew sleeping compartments used during the FRET experiments. As a consequence, these experiments can be compared with the FRET experiments, although during the latter, (bare) charges of 8 kg and 12 kg TNT were used.

The crew aft sleeping compartment (height: 2.2 m, length: 4.3 m, width: 7.2 m - 9.4 m) was cleared as much as possible of all obstacles. The damage to the compartments due to the previous 2 and 5.5 kg TNT experiments was not repaired. Only the upper deck was provisionally repaired.

A venting hole (diameter 40 cm) was made at the centre of the SB hull of the experiment compartment to simulate the hull's penetration by a warhead and to improve the venting of the compartment after the experiment took place.

The charge used during this particular experiment was a cast charge of approximately cylindrical geometry with L/D=1 and D=238 mm resulting in a charge weight of 15 kg TNT. The charge was located in the centre of the compartment at midheight. The charge was ignited at its centre with one electrical detonator (No. 8) and a booster of three RDX cartridges (L/D=1, D=50 mm). The geometry of the charge and an impression of the experimental set-up are shown schematically in Figures 2 and 3.
Note that the location of the charge during this particular experiment corresponds with the location of the 2 kg TNT charge. The 5.5 kg TNT experiment in this compartment was located in a different position. Therefore the results of the 5.5 kg TNT experiment cannot be related directly with the results of the 2 and 15 kg TNT experiments.
An impression of the effects of this experiment is given in Figure 4.

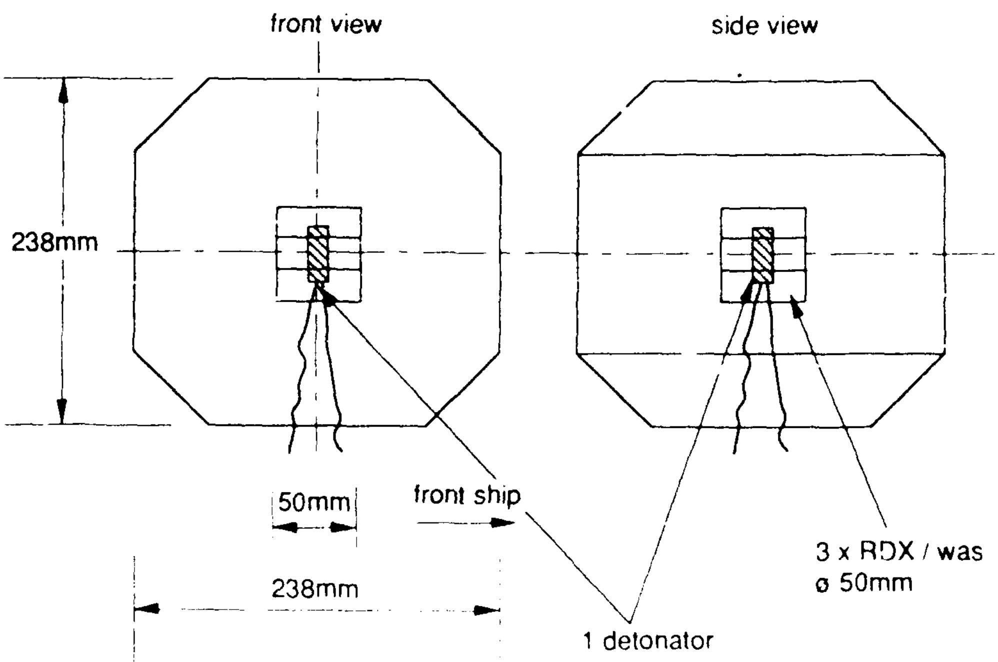


Figure 2 Geometry of the charge

Figure 3 Impression of the compartment before the experiment

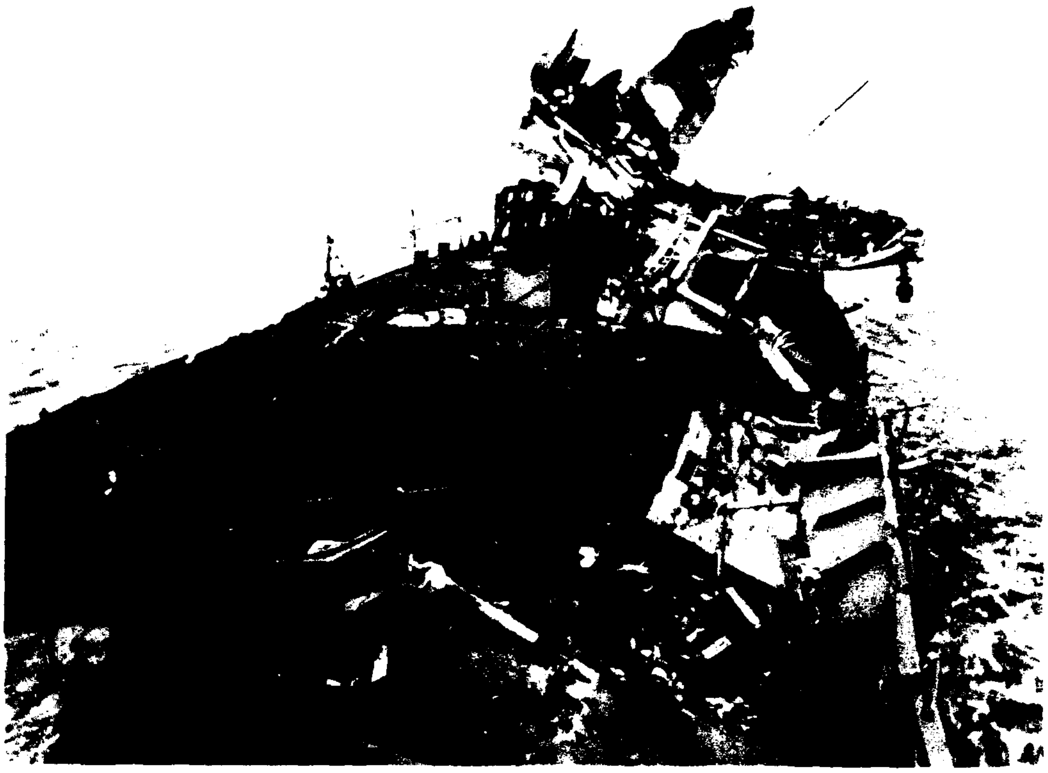


Figure 4 Impression of the demolishing effects of the 15 kg TNT experiment

3 PRESSURE MEASUREMENT

3.1 Position of the pressure transducers

To measure the overpressure, eight piezo-electric pressure transducers B1-B8 were used, all mounted in the experiment compartment. B1 and B2 were mounted on the hull of the frigate whereas B3-B8 were flush mounted on the bulkheads. It must be noted that transducer B1 was located in the hull in the vicinity of the 40 cm diameter venting hole. All transducers were mounted at about midheight in the compartment. The positions of the transducers are summarized in Table 2 and shown schematically in Figure 5.

Table 2 Position of pressure transducers (B)

Device	Height	Mounting position	
B1 (1)	115 cm	on hull SB,	155 cm from BHD 78
B2	115 cm	on hull PS,	155 cm from BHD 78
B3	114 cm	on BHD 78,	35 cm from CL
B4	114 cm	on BHD 78,	176 cm from CL
B5	114 cm	on BHD 78,	328 cm from CL
B6	115 cm	on BHD 71,	368 cm from CL
B7	114 cm	on BHD 71,	259 cm from CL
B8	114 cm	on BHD 71,	102 cm from CL

(1) in vicinity of the venting hole

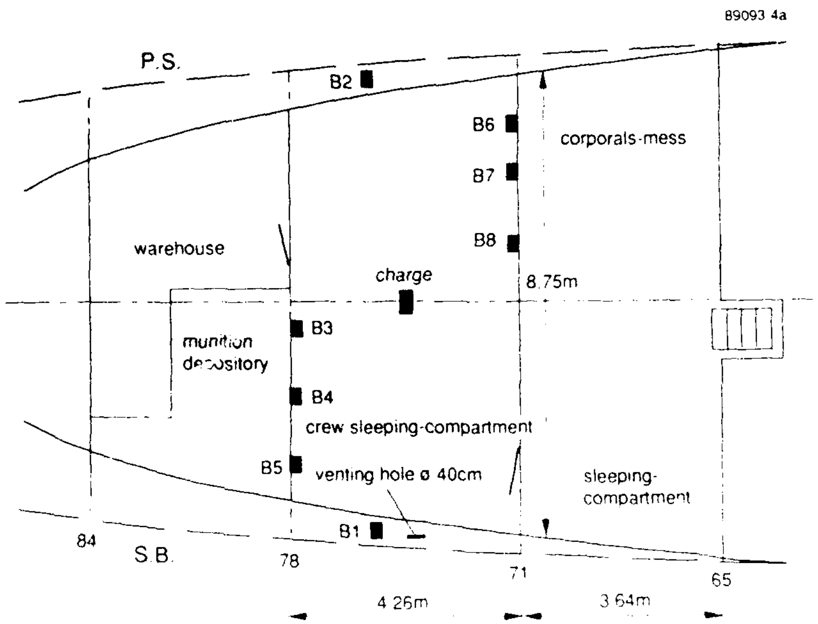


Figure 5 Schematic illustration of the positions of the pressure transducers

3.2 Discussion of the pressure measurements

In order to get an impression of the accuracy of the recordings as presented in Figures 6-8, the first peak pressure and the arrival time of each signal were determined and gathered in Table 3. The theoretical predictions, based on a simplified, centrally ignited, spherical charge (Baker, 1983, Figures 2.45 and 2.46) are also included in this table.

Table 3 Comparison of experimental and theoretical (first) peak pressure and arrival time

Device	d(D,C)	Z	Peak pressure		Arrival time	
			Exp.	Theor.	Exp.	Theor.
	[m]	[m/kg$^{1/3}$]	[kPa]	[kPa]	[ms]	[ms]
B1$^{(1)}$	4.25	1.72	506	1112	2.6	3.4
B2	4.25	1.72	1503	1112	2.4	3.4
B3	2.15	0.87	10020	8107	0.9	0.9
B4	2.75	1.12	2381	2815	1.6	1.4
B5	3.95	1.60	2202	1287	2.8	2.9
B6	4.25	1.72	1979	1112	3.3	3.4
B7	3.35	1.36	3291	1678	2.4	2.1
B8	2.35	0.95	9347	6020	1.3	1.0

(1) : in vicinity of venting hole

d(D,C) : distance between Device and Charge

Z : scaled distance [m/kg$^{1/3}$]

Theoretical values for a centrally ignited, spherical charge (Baker, 1983, Figures 2.45 and 2.46)

From this table it appears that the experimental arrival time generally agrees very well with the theoretical prediction, although the experimental arrival time of B1 and of B2 is 1 ms later than the theoretical prediction. Regarding the peak pressures, it appears that the experimental and theoretical values agree reasonably well for some of the devices. Other devices even show an overshoot of the theoretical peak pressure value of up to a factor 2 (which, however, is still less than the overshoot noted by the 2 and 5.5 kg TNT experiments). It must be stated however, that some of the experimental peak values are based on 'small' peaks, the extrapolated peak values correspond much better.

The arrival time of the shock front will not be influenced by the angle of incidence of the shock front and the wall. The (peak) face-on pressure however depends on the angle of incidence. The theoretical predictions of the peak face-on pressures were based on a perpendicular incident angle, which is correct for transducers B1, B2, B3 and B4. The remaining devices have a (slightly) different incident angle.

The devices were located almost symmetrically with respect to the charge: devices B1 and B2, devices B3 and B8, devices B4 and B7, and devices B5 and B6. Due to reflections, the influence of the (local) geometry will become more pronounced at a later stage.
Consider the first part of the recordings of these device combinations in more detail:

1 Devices B1 and B2: Comparing these signals, it appears that the first peak pressures show a remarkable correspondence, which at a later stage is distorted. The negative response of B1 shortly after the arrival of the shock wave is comparable with the 2 and 5.5 kg TNT experiments and cannot be explained.
2 Devices B3 and B8: The correspondence of the shape of the signals is remarkable, although a difference in arrival time of 0.4 ms can be noted. A slight difference in the exponential decay is noticeable.
3 Devices B4 and B7: These two devices show no correspondence, the arrival times differ considerably. However, disregarding the first extreme peak of B7, the peak values correspond well. The later peaks show a different reflection process.
4 Devices B5 and B6: The shape and peak pressure show a close resemblance although the arrival times differ remarkably. The overall impression is obscured by the temperature drift of the transducers.

Drift in the blast signals may be due to temperature influences. From the geometry of the test set-up it is evident that the pressure devices were (almost) symmetrically mounted with respect to the centre of the charge. The simplification made for the theoretical predictions did not hold, but were not so violated as during the previous 2 and 5.5 kg TNT experiments in the same compartment. The discrepancy in the response of the symmetrically mounted devices can thus only be made plausible by taking into account the geometry of the charge, the way the charge is ignited and the venting hole near device B1.
Notwithstanding these considerations, the pressure recordings as presented in this chapter seem to be reliable and of good quality.

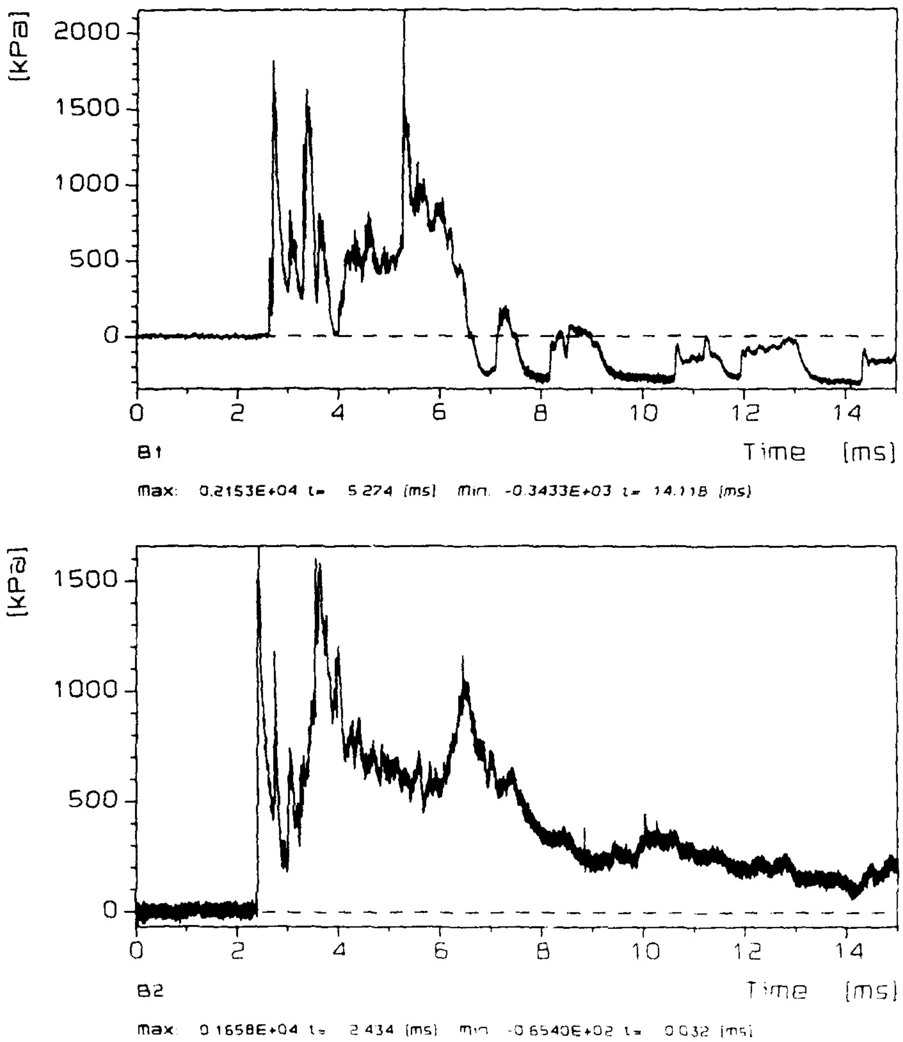


Figure 6 Pressure signals B1 (SB hull) and B2 (PS hull)

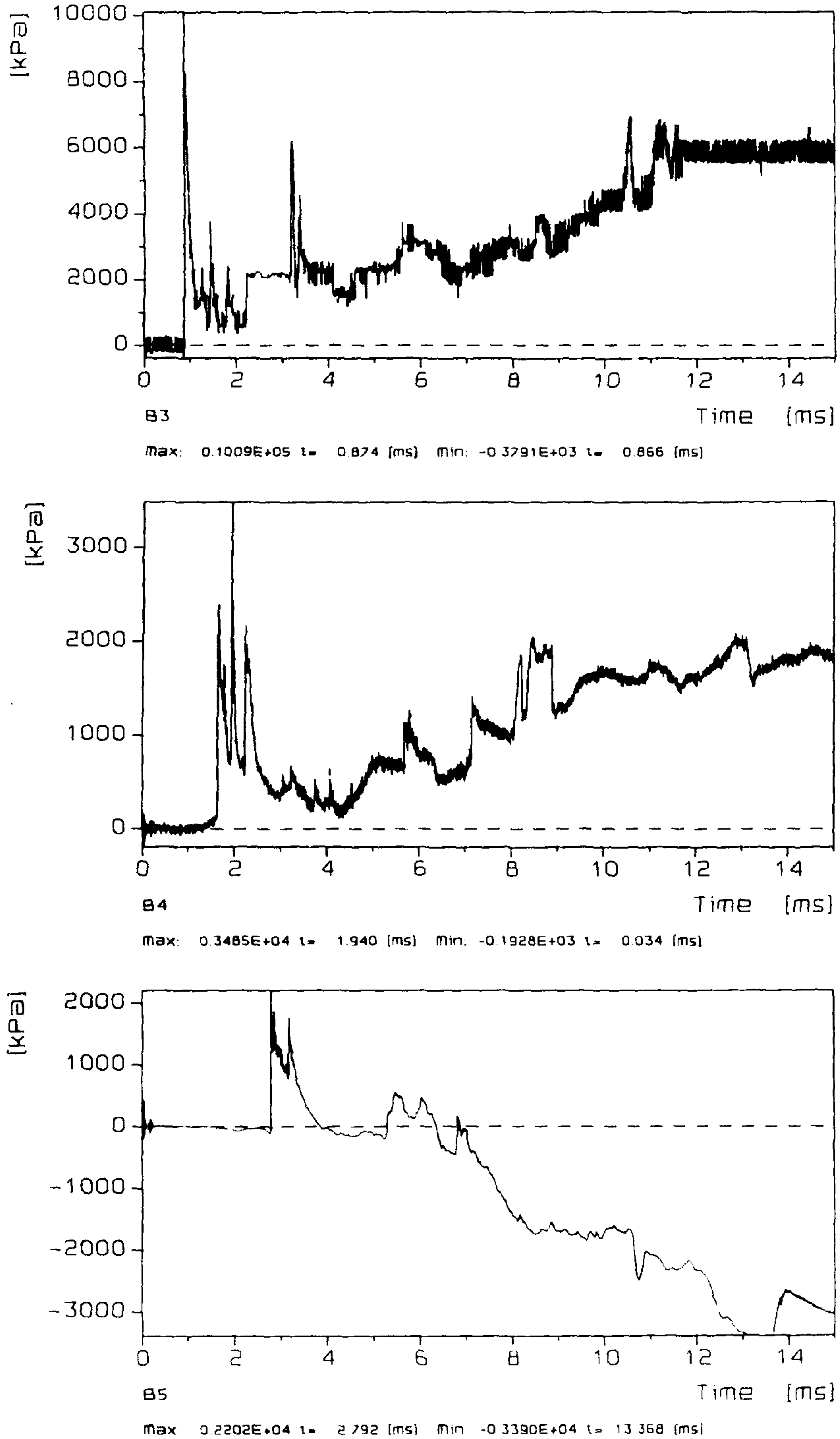


Figure 7 Pressure signals B3, B4 and B5 (BHD 78)

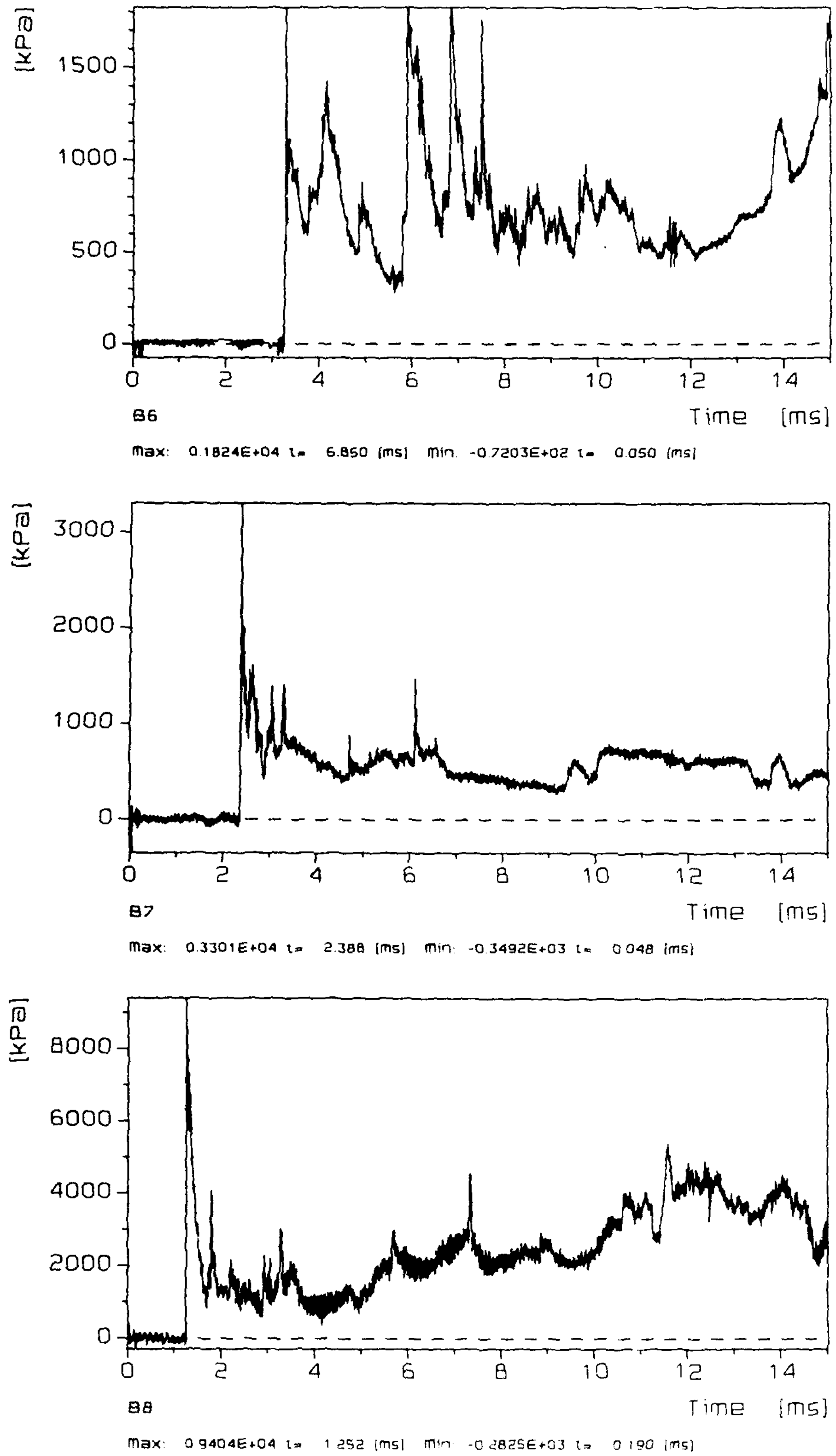


Figure 8 Pressure signals B6, B7 and B8 (BHD 71)

4 QUASI-STATIC PRESSURE MEASUREMENT

4.1 Position of the quasi-static pressure transducers

The quasi-static pressures were registered with piezo resistive transducers at seven different locations (Q1-Q7). Two transducers (Q1, Q2) were placed in the crew aft sleeping quarter. The remaining transducers were placed in the adjacent compartments, i.e. three transducers (Q3, Q4, Q5) in the corporals' sleeping quarters/mess, one (Q6) in the munition depository and one (Q7) in the warehouse. The positions of the transducers are summarized in Table 4 and shown schematically in Figure 9.

Table 4 Position of the quasi-static pressure transducers

Device	Height	Position
Q1 (1)	125 cm	15 cm in front of the SB hull, experiment compartment
Q2	127 cm	17 cm in front of the PS hull, experiment compartment
Q3	118 cm	246 cm from SB, on BHD 65, corporals' sleeping quarters/mess
Q4	113 cm	305 cm from PS, on BHD 65, corporals' sleeping quarters/mess
Q5 (2)	115 cm	200 cm behind door BHD 71, hull SB, corporals' sleeping quarters/mess
Q6	113 cm	141 cm from BHD 78, munition depository
Q7	113 cm	160 cm from BHD 78, warehouse

(1) in vicinity of venting hole

(2) membrane direction BHD 65 (face off)

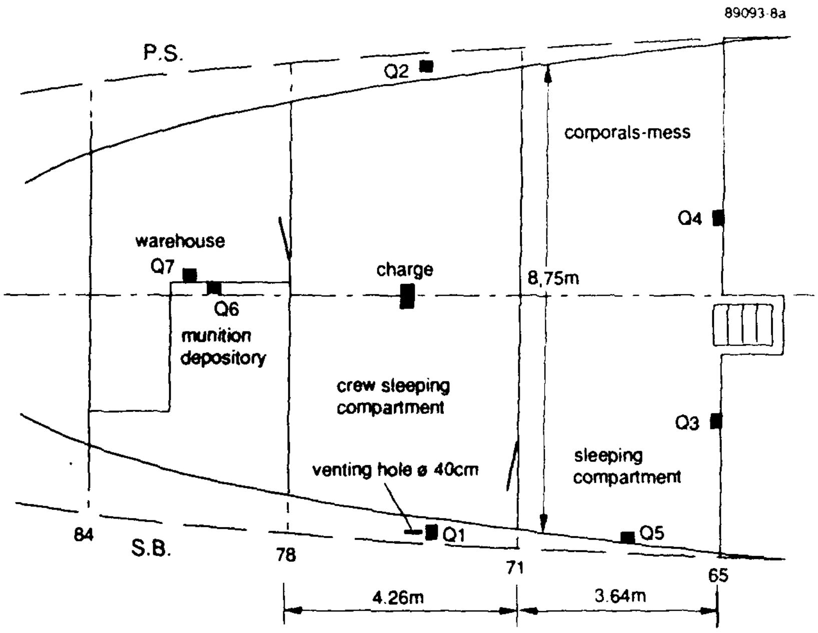


Figure 9 Schematic illustration of the positions of the quasi-static pressure transducers

4.2 Discussion of the quasi-static pressure measurements

The recorded quasi-static pressures are presented in Figures 10, 11, 12 and 13. To get a good impression and interpretation of the quasi-static pressure recorders, it must be noted that during this experiment, the experiment compartment, as well as the adjacent compartments and the upper deck, were extensively damaged.

Transducer Q1 malfunctioned after 25 ms, which is probably due to the extreme test situation. For the first 25 ms however, the registered signal seems reasonably good. Transducer Q2 performs well over an even longer period.
Devices Q3, Q4 and Q5 were mounted in the corporals' mess and sleeping quarters, which were one compartment. Walls etc. were removed before the experiments took place. This compartment is connected to the experiment compartment only by the door in BHD 71, and ruptured in the

bulkhead due to the 2 and 5.5 kg TNT experiments. This watertight door however was blown out of its frame during this (the 15 kg TNT) experiment, as well as the remaining bulkhead. The pressure in this compartment is due to the collapse of the door and wall. From the behaviour of Q3, Q4 and Q5 it may be deduced that the door/wall collapsed approximately 10 ms after the charge ignited. For up to 30 ms the reaction products flow into the compartments, while at t=30 ms the pressure in the adjacent compartment is comparable with the pressure in the experiment compartment. From 30 ms onwards, the decay of the quasi-static pressure is mainly due to the venting of the combined compartments.
Note that the membrane of Q5 is in the direction of BHD 65. It appears that Q4 and Q5 show a close resemblance, while Q3 differs slightly. This may be attributed to the location of device Q3: behind the door in BHD 71. The different behaviour of Q3 was also apparent during the 2 and 5.5 kg TNT experiment earlier that day. Transducer Q4 malfunctioned which, however, did not seem to influence the registered signal.

Note that the munition depository (Q6) has (originally) no direct connection with the experiment compartment, this compartment could (originally) only be reached from the upper deck. There were ruptures in BHD 78 due to the 2 and 5.5 kg TNT experiments. Q6 starts reacting after 5 ms which may be due to leakage, while at t=10 ms, the signal starts to increase drastically. From this may be deduced that the rupture process of BHD 78 and BHD 71 correspond.

The warehouse (Q7) could originally only be reached from the experiment compartment by a door. Due to the previous 2 and 5.5 kg TNT experiments this door will initially show leakage leading to a small quasi-static pressure increase at t=5 ms. Again, a strong increase in the quasi-static pressure is evident in this signal, due to the rupture of BHD 78. This led to the unexpected exposure of the transducer, resulting in an overload.

From the assumptions of the rupture of BHD 71 and BHD 78 at t=10 ms, the strong pressure drop of Q1 and Q2 in the experiment compartment at t=10 ms can be explained by the drastic enlargement of the experiment compartment.

In Table 5, the arrival time T_a, the maximum pressure P_{max} and time T_{max} are summarized.

Table 5 Quasi-static pressure measurement

Device	T_a [ms]	P_{max} [kPa]	T_{max} [s]
Q1	2.3	900	6.5
Q2	2.2	800	6.5
Q3	10.5	220	30
Q4	10.6	100	30
Q5	8.9	200	30
Q6	4.8	160	30
Q7	4.8	overload	

Comparing the arrival time of devices Q1 and Q2 with the arrival time of pressure transducers B1 and B2, as summarized in Table 3, shows a close resemblance.

A comparison with theoretical values is in the first instance only possible for Q1 and Q2, mounted in the experiment compartment. According to Baker (1983, Figure 3.15), a quasi-static pressure of 540 kPa will be found, based on 15 kg TNT and a compartment volume of 77 m^3. The Weibull distribution leads to 710 kPa. Comparing these values (540 kPa, 710 kPa) with the measured peak values of Q1 and Q2 (900 kPa and 800 kPa) shows a discrepancy.

However, due to the rupture of the bulkheads after 10 ms it is disputable if these peak values may be regarded as quasi-static pressures. Regarding the signals after 30 ms, it appears that the Q1, Q2 Q3, Q4, Q5 and Q6 recorded a maximum quasi-static pressure of 150-200 kPa. Regarding these compartments as one compartment with a volume of ±140 m^3, it appears that the theoretical predictions of Baker and Weibull result in 380 kPa and 450 kPa. This value (±400 kPa) must be regarded as an upper limit for the QSP, due to the venting through the upper deck which was also demolished.

From this it may be concluded that the quasi-static pressure recordings as presented in this chapter seem to be reliable.

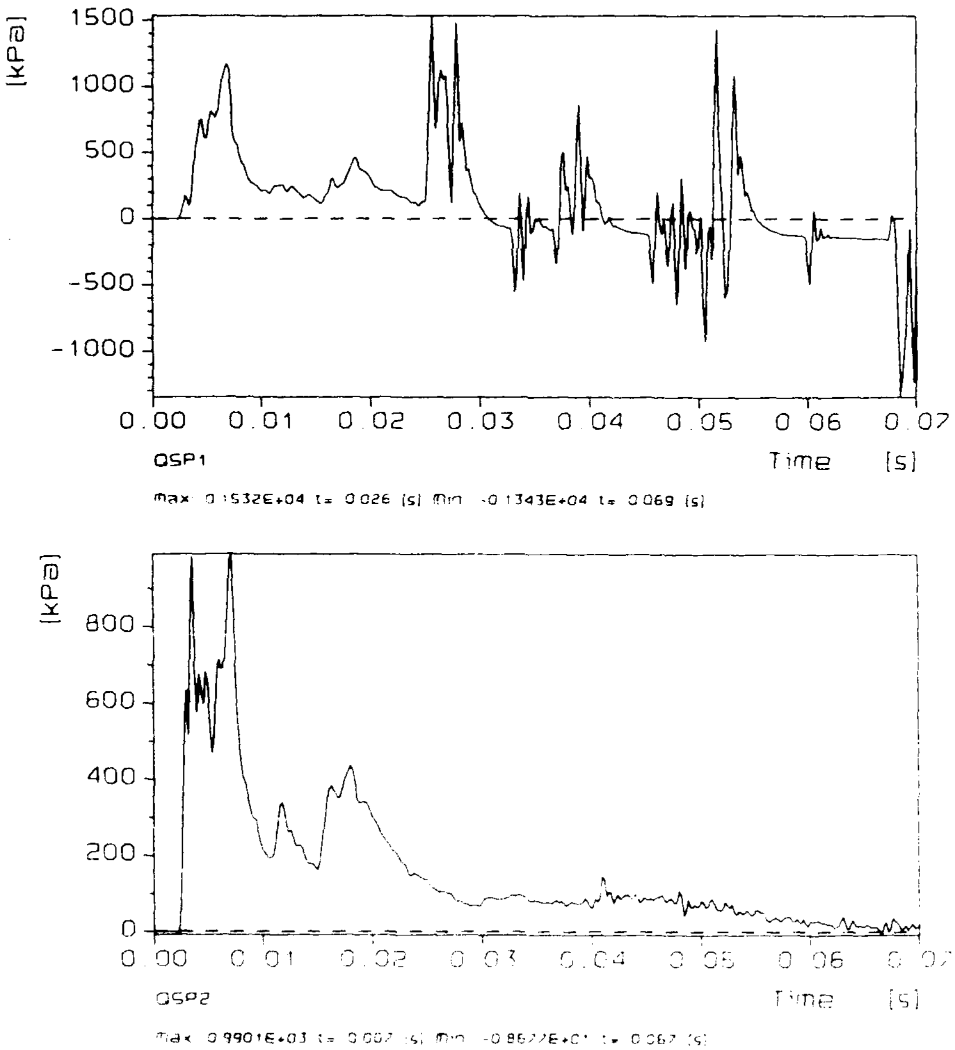


Figure 10 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

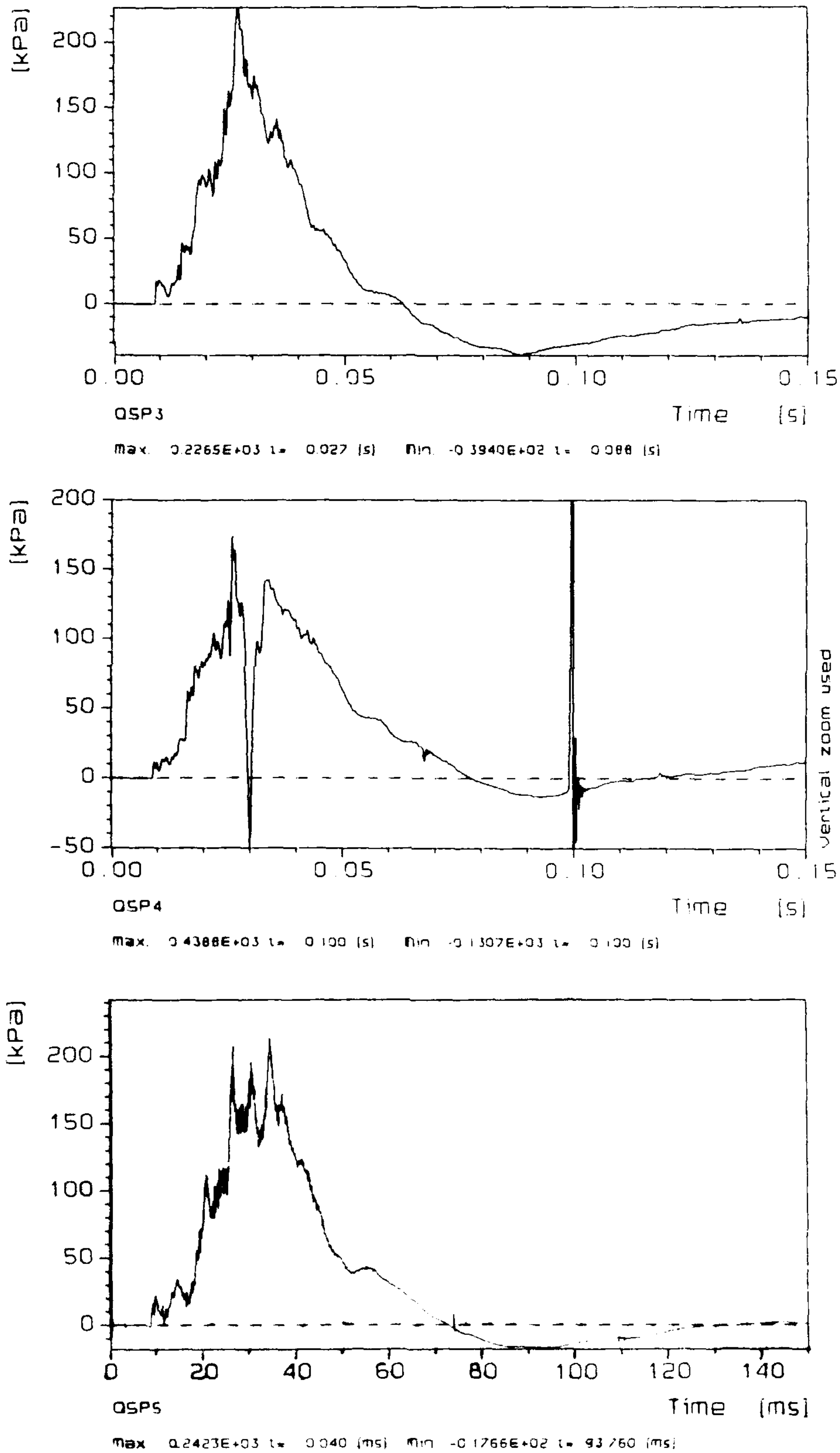


Figure 11 Quasi-static pressure signals Q3, Q4 and Q5 (corporals' mess/sleeping compartment)

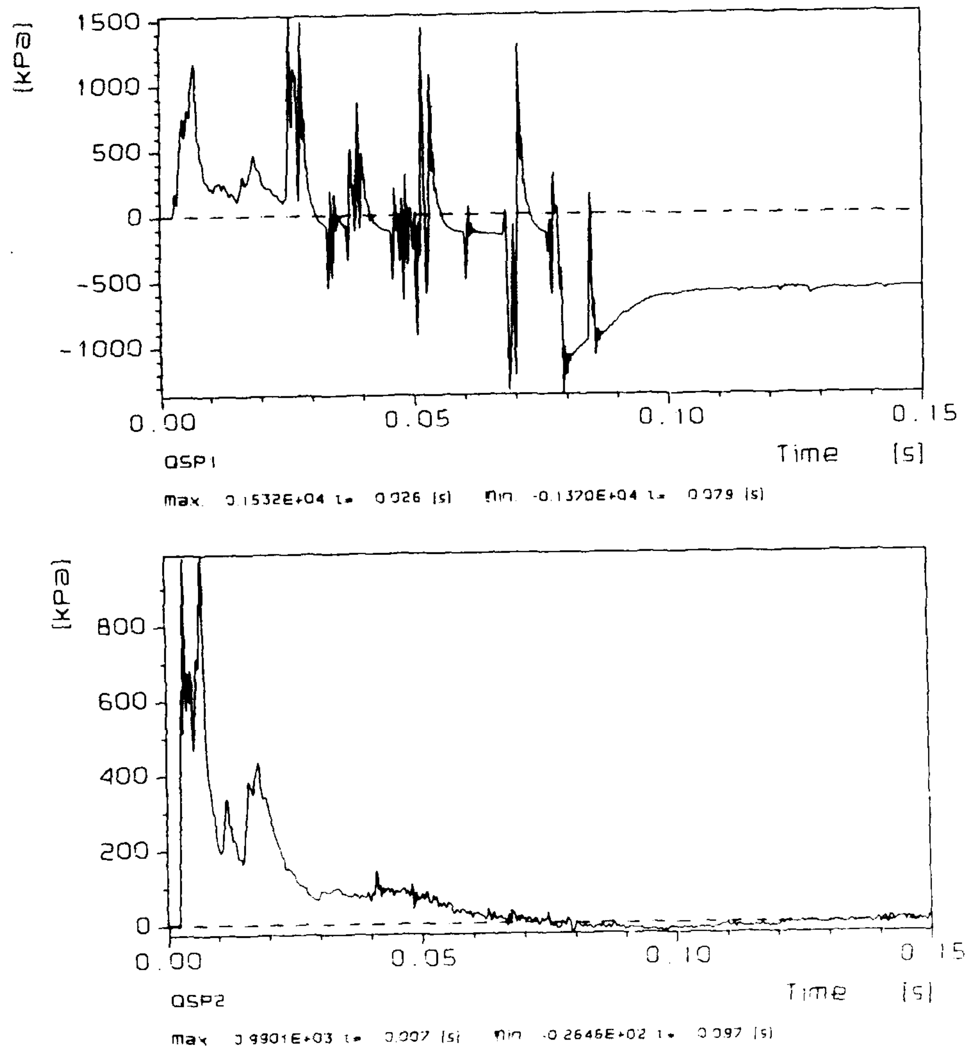


Figure 12 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

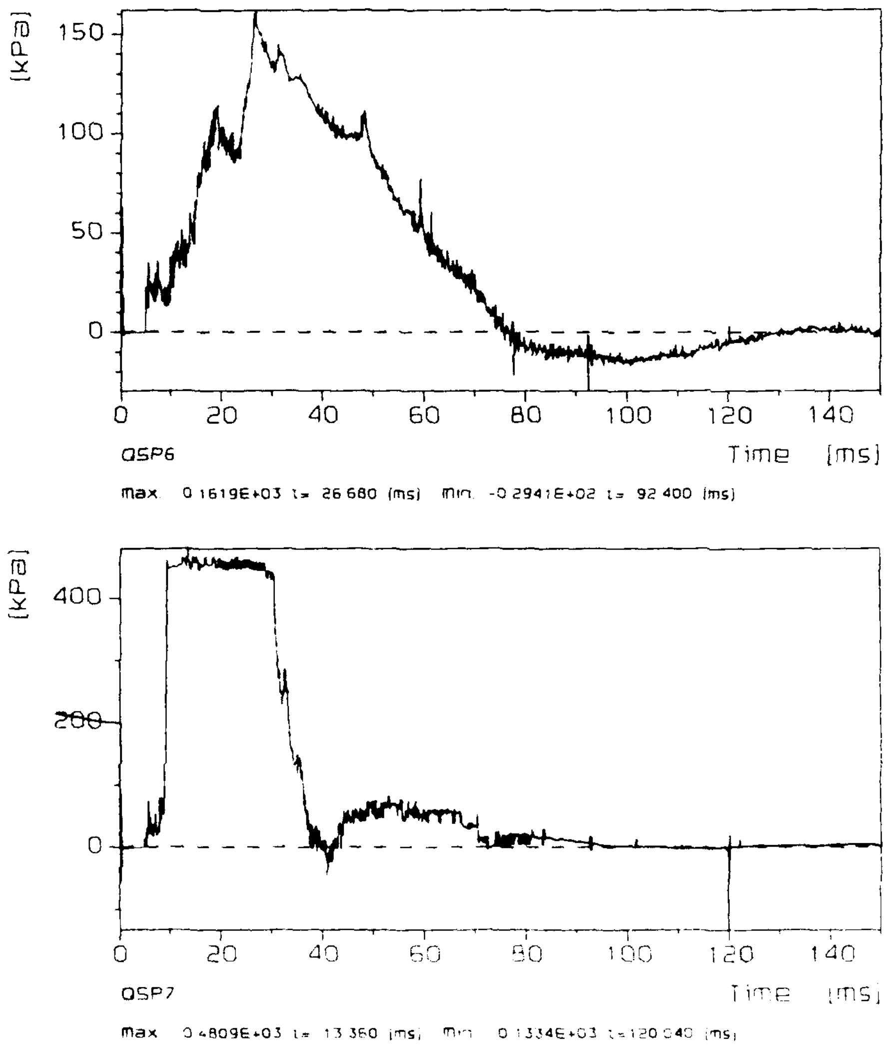


Figure 13 Quasi-static pressure signals Q6 (munition depository) and Q7 (warehouse)

5 STRAIN MEASUREMENT

5.1 Position of the strain gauges

The strain was measured using 2% and 10% strain gauges in twenty-two positions (S1-S22) during the experiment. Some of the strain gauges were placed singly while others were placed in pairs, opposite each other.
The positions of the strain gauges are summarized in Tables 6-8 and shown schematically in Figures 14-17; a subdivision was used.

To visualize the location of the strain gauges, the following notation was used:

▮ : 2% strain gauge, single, front side

▯ : 2% strain gauge, single, back side

d ▮ : 2% strain gauge, double, both sides

-▮- : 10% strain gauge, single, front side

-▯- : 10% strain gauge, single, back side

d -▮- : 10% strain gauge, double, both sides

The "front side" or "back side" description is related to the plane of view as shown in the figures.

Table 6 Position of the strain gauges on the hull

Device	Range	Height	Mounted on:
S1	2%	105.0 cm	Frame 74 SB
S2	2%	104.0 cm	Frame 74, PS

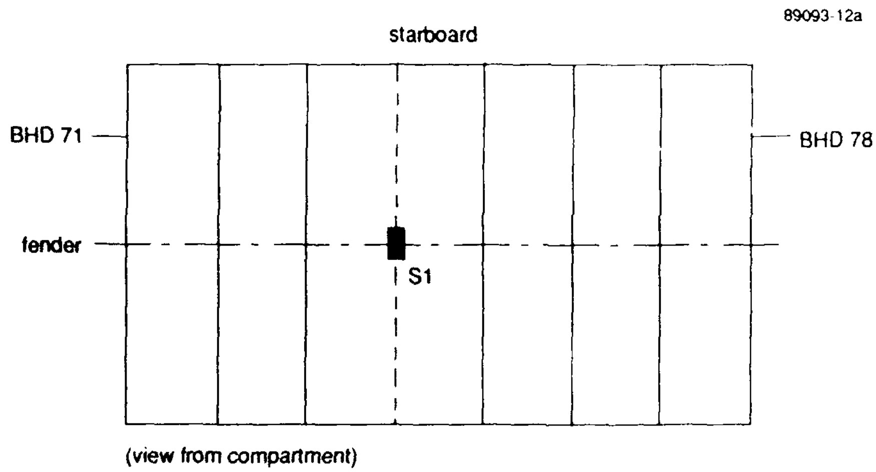


Figure 14 Schematic illustration of strain gauge position S1 (SB)

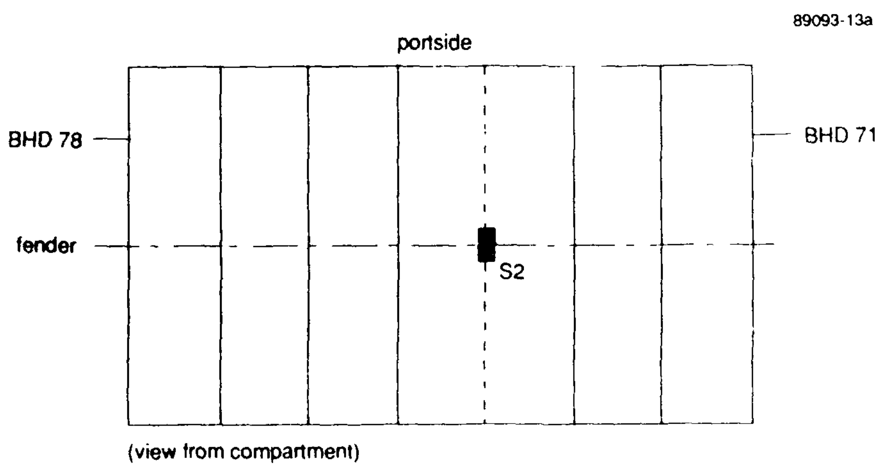


Figure 15 Schematic illustration of strain gauge position S2 (PS)

Table 7 Position of the strain gauges on BHD 71

Device	Range	Opposite	Height	Mounted on:
S3	10%	S22	80 cm(2)	centre door
S4(1)	10%	---	114 cm	wall, back side stiffener
S5	2%	S6	114 cm	10 cm beside stiffener
S6(1,*)	2%	S5	113 cm	10 cm beside S4
S7(*)	10%	S8	30 cm	on stiffener
S8(1)	10%	S7	30 cm	wall, back side stiffener
S9	2%	S10	30 cm	wall, 10 cm beside stiffener
S10(1,*)	2%	S9	30 cm	wall, 10 cm beside S8
S11(*)	10%	S12	6 cm	wall, 10 cm beside stiffener
S12(1)	10%	S11	6 cm	wall
S13	2%	---	73 cm(3)	on stiffener
S22(1)	10%	S3	80 cm(2)	centre door

(1) in experiment compartment

(2) from bottom side door

(3) beneath ceiling (J-deck)

(*) malfunctioned during previous 2 and/or 5.5 kg TNT experiments

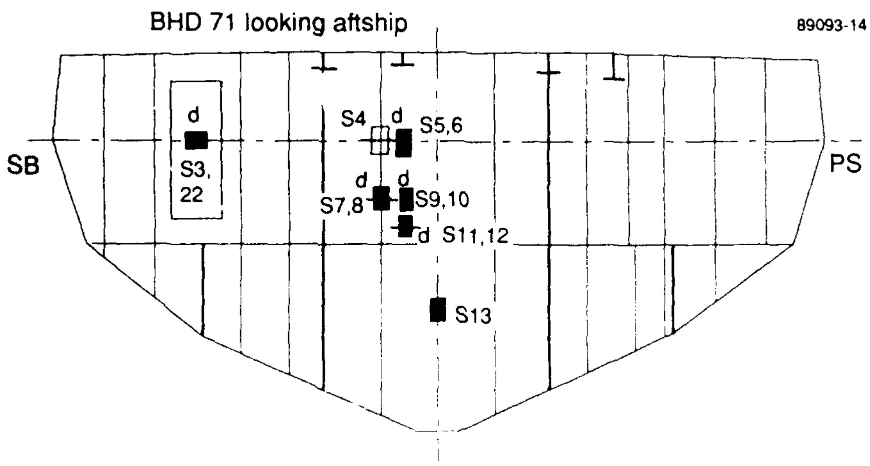


Figure 16 Schematic illustration of strain gauge positions on BHD 71

Table 8 Strain gauge positions on ceiling and upper deck

Device	Range	Opposite	Mounting place:
S14	10%	S15	see S15, on deck
S15(1)	10%	S14	28 cm from BHD 78, 10 cm PS from CL
S16	10%	S17	see S17, on deck
S17(1)	10%	S16	101 cm from BHD 71, 135 cm from PS girder
S18(*)	10%	S19	see S19, on deck
S19(1)	10%	S18	15 cm from BHD 71, 40 cm from PS girder
S20	10%	S21	see S21, on deck
S21(1)	10%	S20	15 cm from BHD 71, 40 cm from SB girder

(1) in experiment compartment

(*) malfunctioned during 2 or 5.5 kg TNT experiments

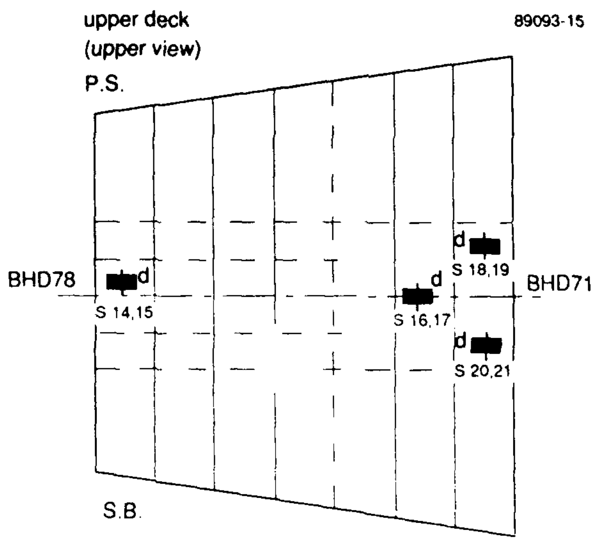


Figure 17 Schematic illustration of position of strain gauges on ceiling and upper deck (J-deck) of explosion compartment

5.2 Discussion of the strain measurements

The strain signals are shown on different time-scales in Figures 18-22. The time-scale used in the figures is, in a number of cases, determined by the moment that the strain gauge malfunctioned. S6, S7, S10, S11 and S19 are omitted from this report due to a malfunction during the previous 2 or 5.5 kg TNT experiments, or this experiment. Opposite-mounted strain gauges are depicted in one figure, enabling a better understanding of the behaviour.

During this experiment, a number of the remaining strain gauges malfunctioned after some time, as summarized in Table 9.

Table 9 Moment of malfunctioning of strain gauge

Experiment compartment:	S1	20 ms,	S2	59 ms,		
BHD 71:	S3	52 ms,	S4	1.5 ms,	S5	28 ms
	S8	2.6 ms,	S9	22 ms,	S12	1.6 ms
Ceiling/upper deck:	S15	120 ms,	S16	130 ms,		
	S20	2.2 ms,	S21	1.6 ms		

It is obvious that the 15 kg TNT experiment damaged a number of strain gauges shortly after the charge ignited. The recordings however show a reliable response up to the moment that they malfunctioned. Most strain gauges indicate a (permanent) elastic-plastic deformation.

The strain gauge couple S14 and S15, glued near a girder, show an 'in-phase' response (longitudal waves). The plate can be regarded as a part of the girder and acts as one of the flanges. Consequently, a bending vibration in the girder is observed as an 'in-phase' vibration in the plate near the girder. Strain gauge couple S16 and S17 appears to be located outside the influence zone of the girder and shows an 'anti-phase' response. Both couples were glued onto the ceiling/deck in the vicinity of a girder.

Special attention was focussed on couple S3 and S22 which was glued onto the watertight door in BHD 71. For up to ±10 ms the 'anti-phase' response behaviour of the strain gauge couple corresponds with the response behaviour of this couple during the 2 and 5.5 kg TNT experiment.

After ±10 ms the 'anti-phase' response behaviour changes into an 'in-phase' response behaviour, which was recorded up to 25 ms. After 25 ms, no correlation exists between these two strain gauge responses. The quasi-static pressure measurements show that at ±10 ms the bulkheads start to collapse, the process of which seems to end at ±30 ms. From this it may be deduced that the

response behaviour of S3 and S22 stems from the demolition and collapse of the watertight door in BHD 71.

From this it is evident that the strain gauge recordings as presented in this chapter have resulted in reliable information (up to the moment that the various strain gauges malfunctioned).

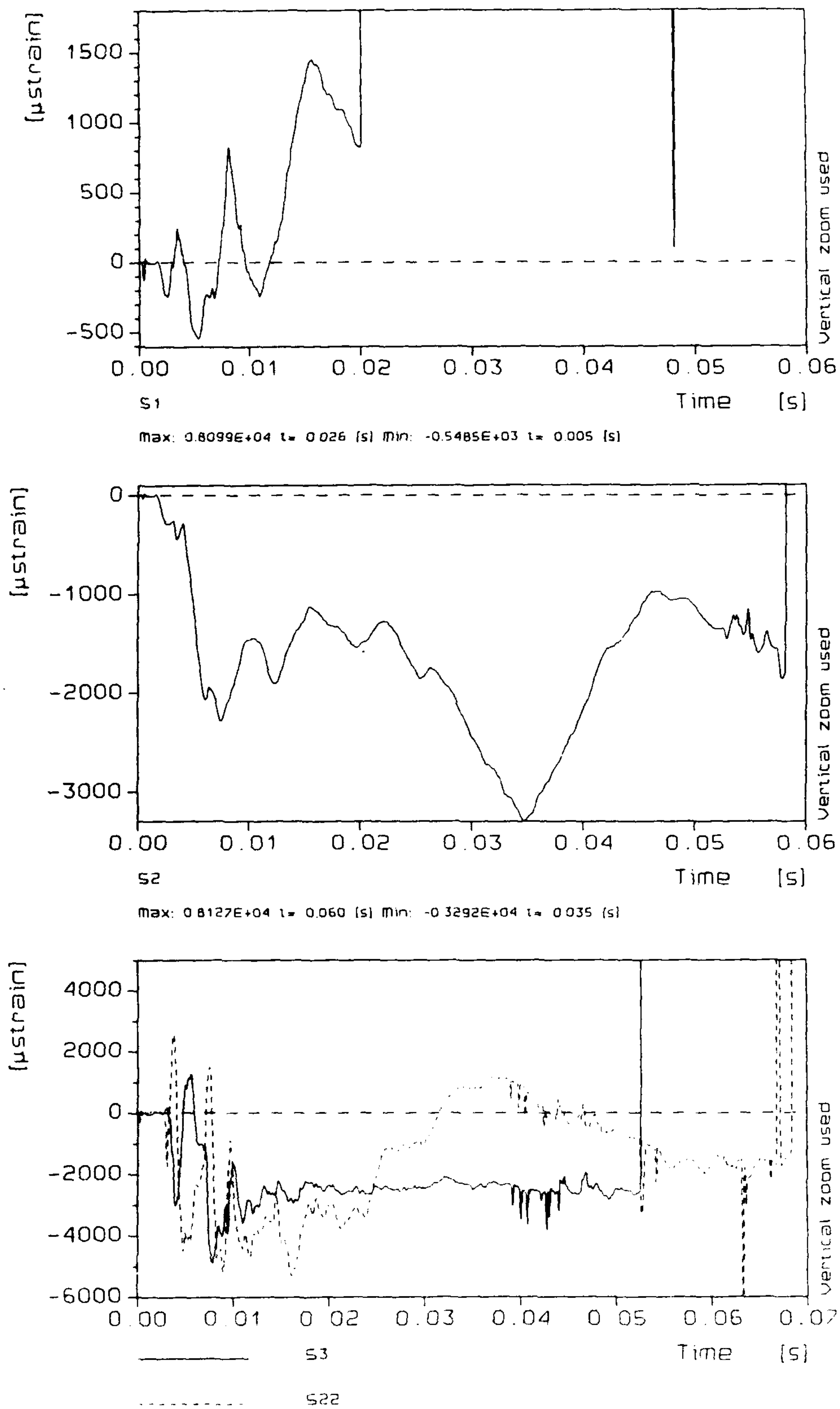


Figure 18 Strain gauge response S1, S2 (hull experiment compartment) S3 and S22 (BHD 71)

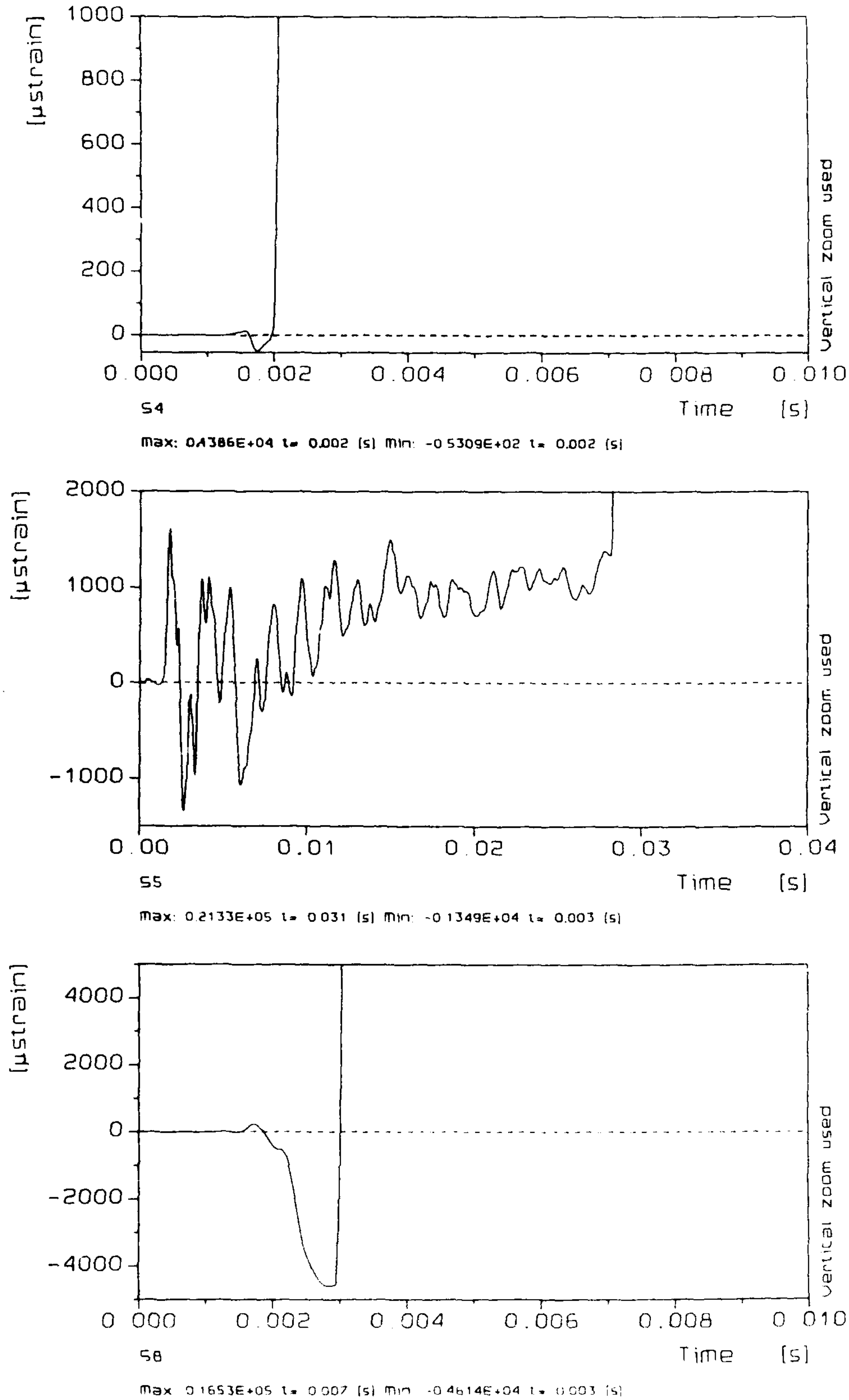
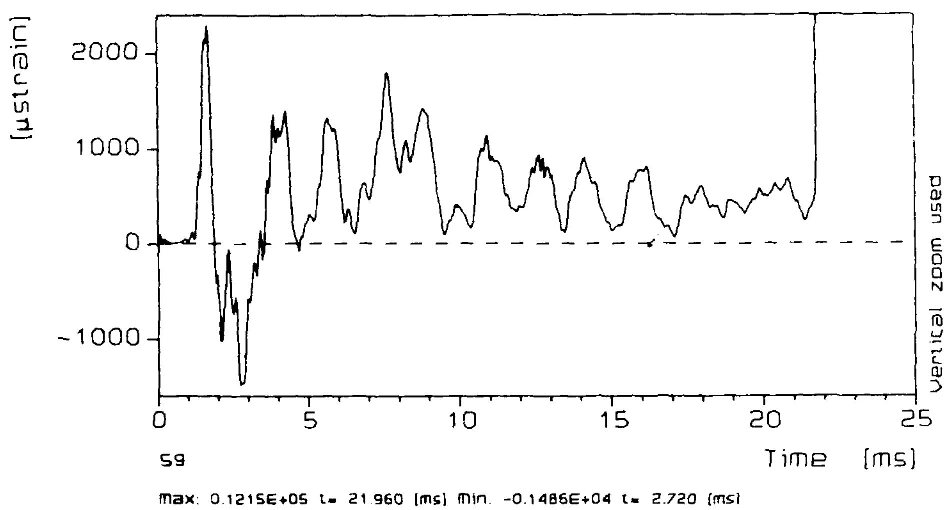
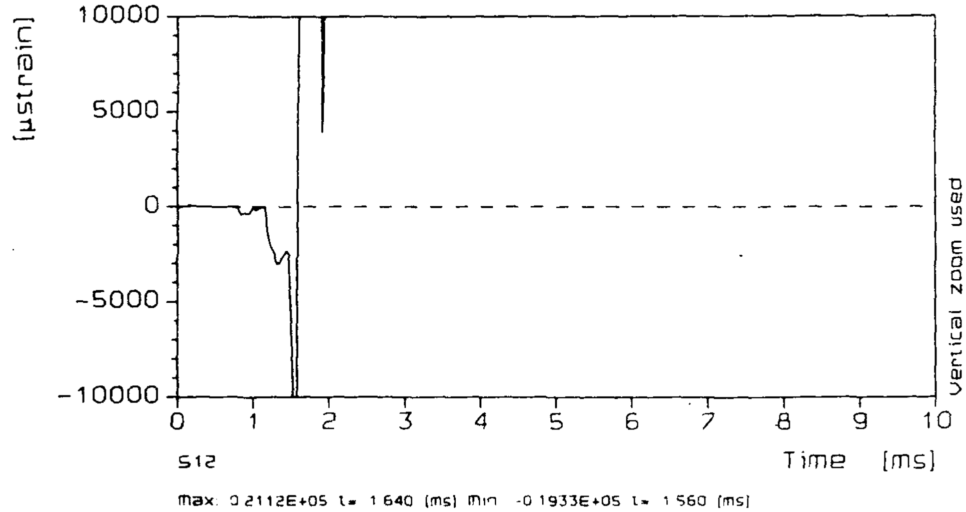


Figure 19 Strain gauge response S4, S5, S8 (BHD 71)





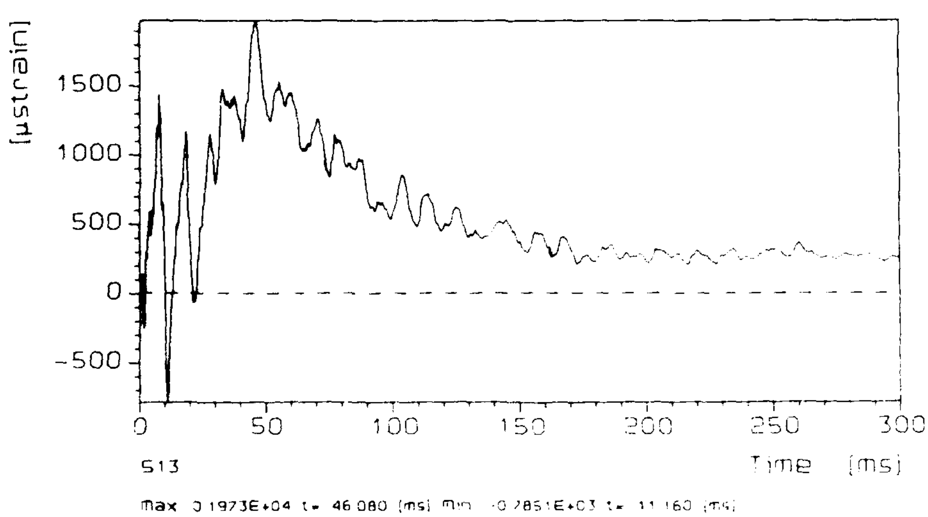


Figure 20 Strain gauge response S9, S12, S13 (BHD 71)

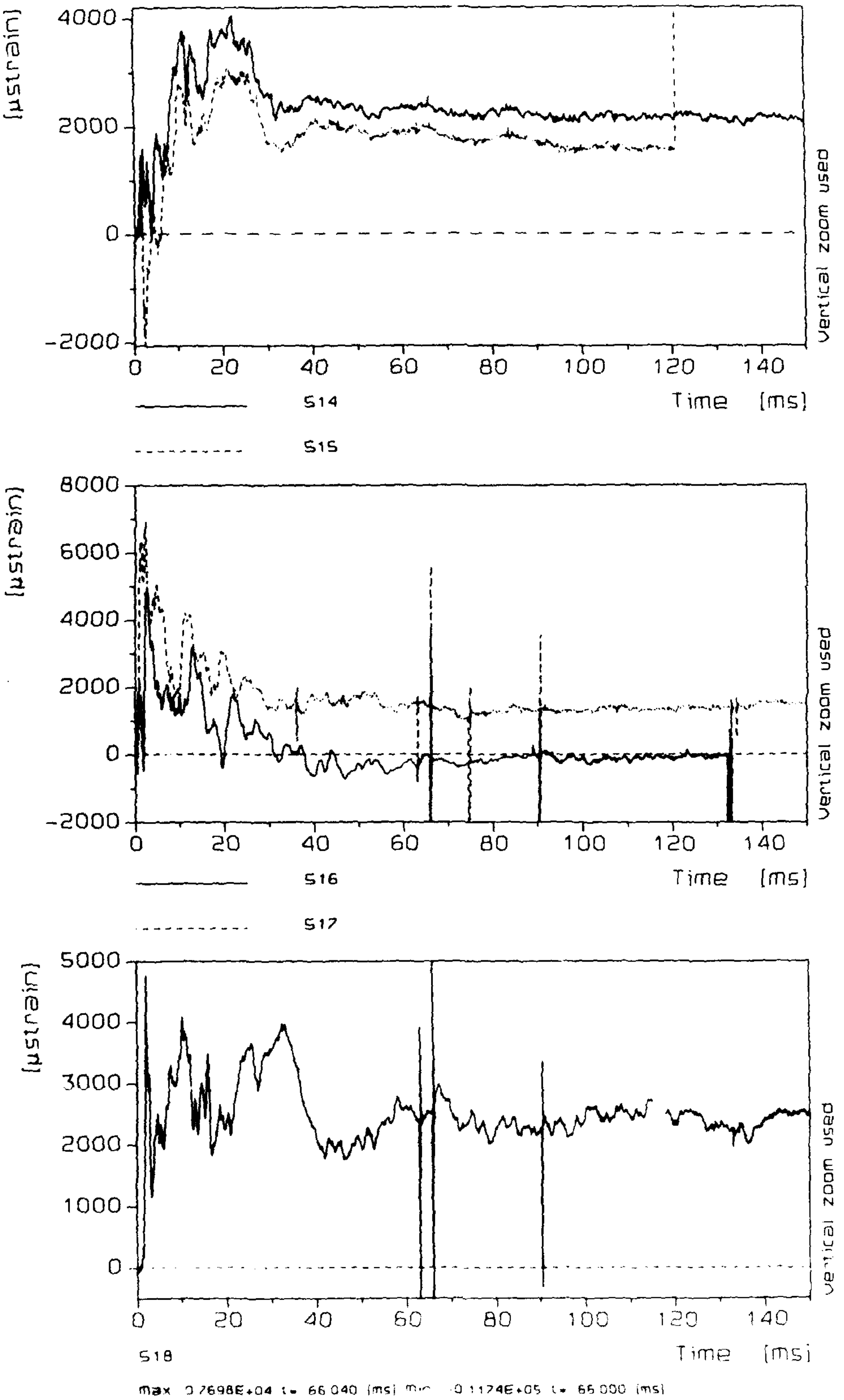


Figure 21 Strain gauge response S14 and S15, S16 and S17, S18 (Ceiling/upper deck)

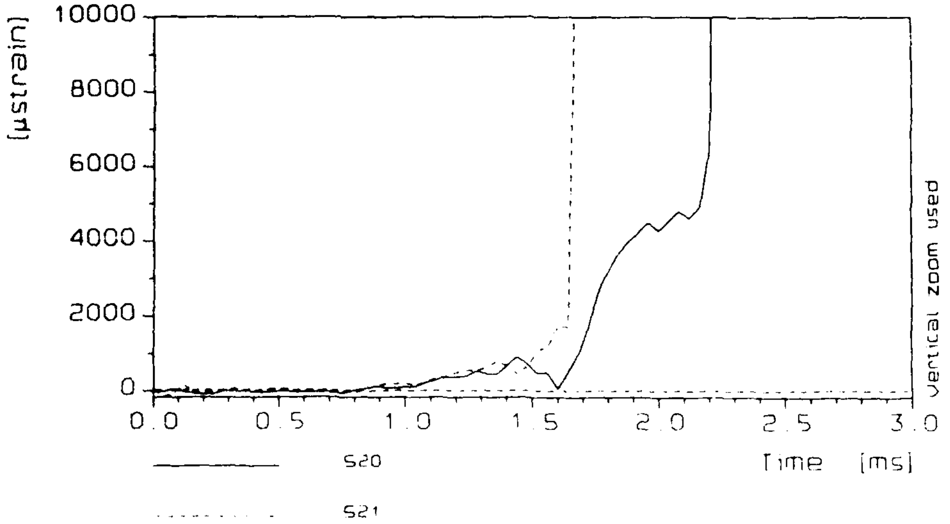


Figure 22 Strain gauge response S20 and S21 (Ceiling/upper deck)

6 ACCELERATION MEASUREMENTS

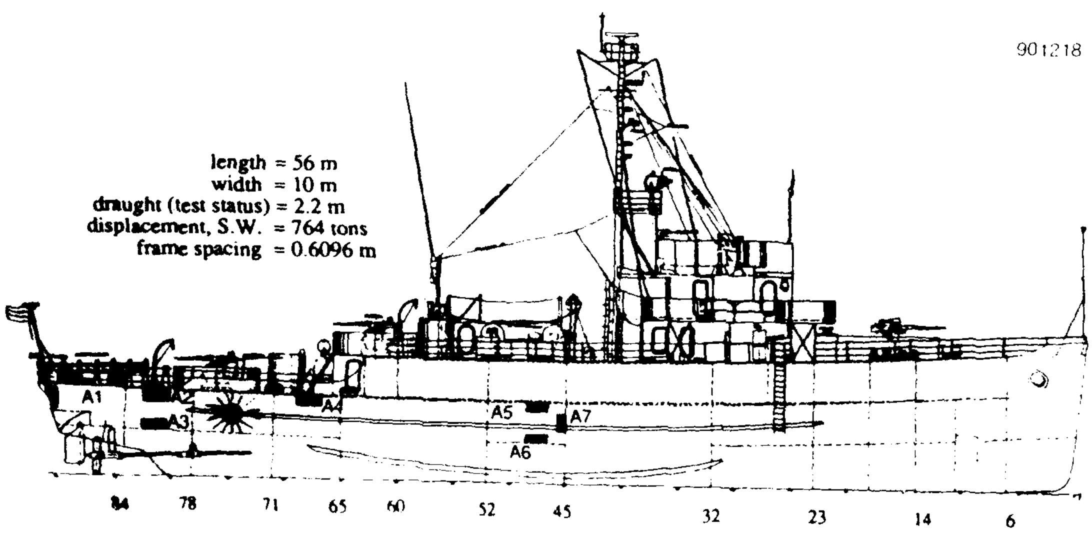
6.1 Position of the accelerometers

During the experiments in the crew aft sleeping compartment, seven accelerometers were used, mounted on the H and J deck, respectively. The location of these accelerometers are summarized in Table 10 and shown schematically in Figures 23 and 24. In these figures, the sensitivity of the transducers is denoted by the length axis of the ■ blocks.

Table 10 Position of the accelerometers (A)

Device	Mounting position		
A1[1]			108 cm beneath ceiling J-deck on CL stiffener
A2	ceiling	J-deck	281 cm from BHD 78, 146 cm SB from CL
A3	floor	J-deck	281 cm from BHD 78, 146 cm SB from CL
A4	ceiling	J-deck	263 cm from BHD 71, on SB girder
A5	ceiling	J-deck	74 cm from BHD 45, on PS girder
A6	floor	J-deck	75 cm from BHD 45
A7[1]			111 cm above floor J-deck on stiffener

[1] vertical direction



Roofdier class frigate

Figure 23 Schematic illustration of the positions of the accelerometers

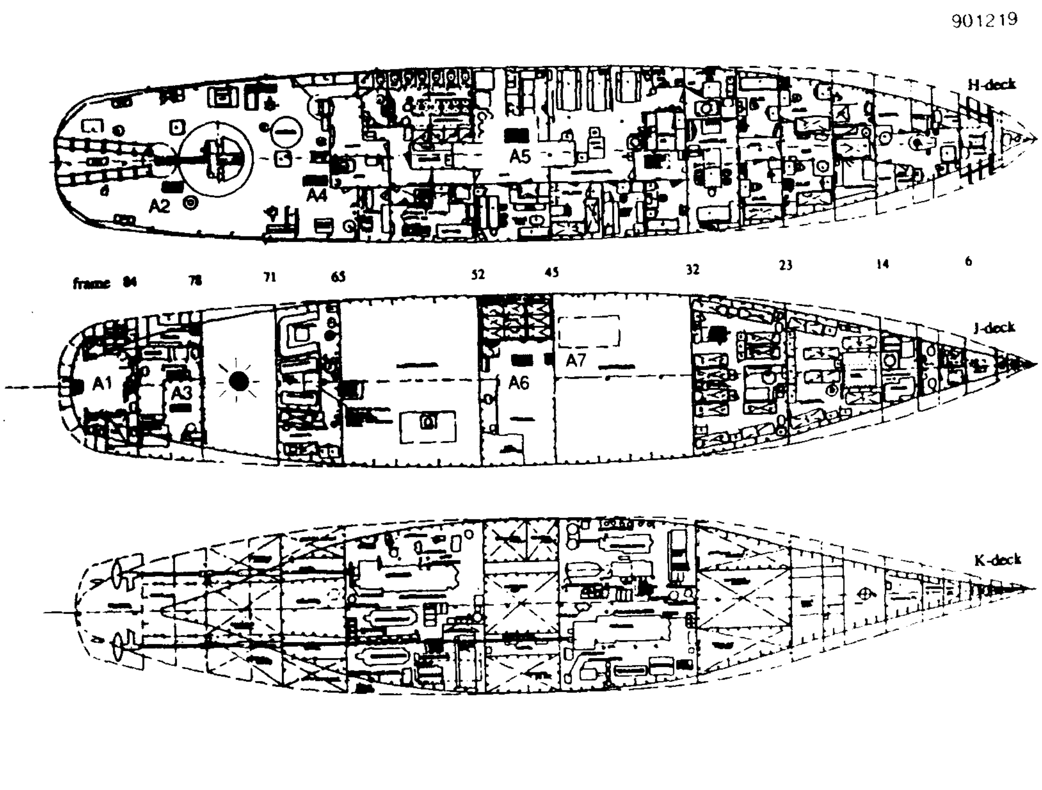


Figure 24 Schematic illustration of the positions of the accelerometers

6.2 Discussion of the acceleration measurements

The results of the acceleration measurements are shown in Figures 25-31. A distortion of the acceleration signals of 50 Hz was removed. In addition, a third order low pass Butterworth filter (1.5 kHz) was used to suppress high frequency influences. Drift correction was necessary to integrate the acceleration signals with respect to the time, resulting in velocity and displacement signals. Drift is however still noticeable in some of the displacement signals. It will be obvious that these rather ad hoc digital signal analysis techniques may influence the presented velocity and displacement signals in an unpredictable way.

Additionally, the shock spectra are presented in Figures 32-38. The positive and negative residual spectra are identical because these figures present the undamped shock spectra.

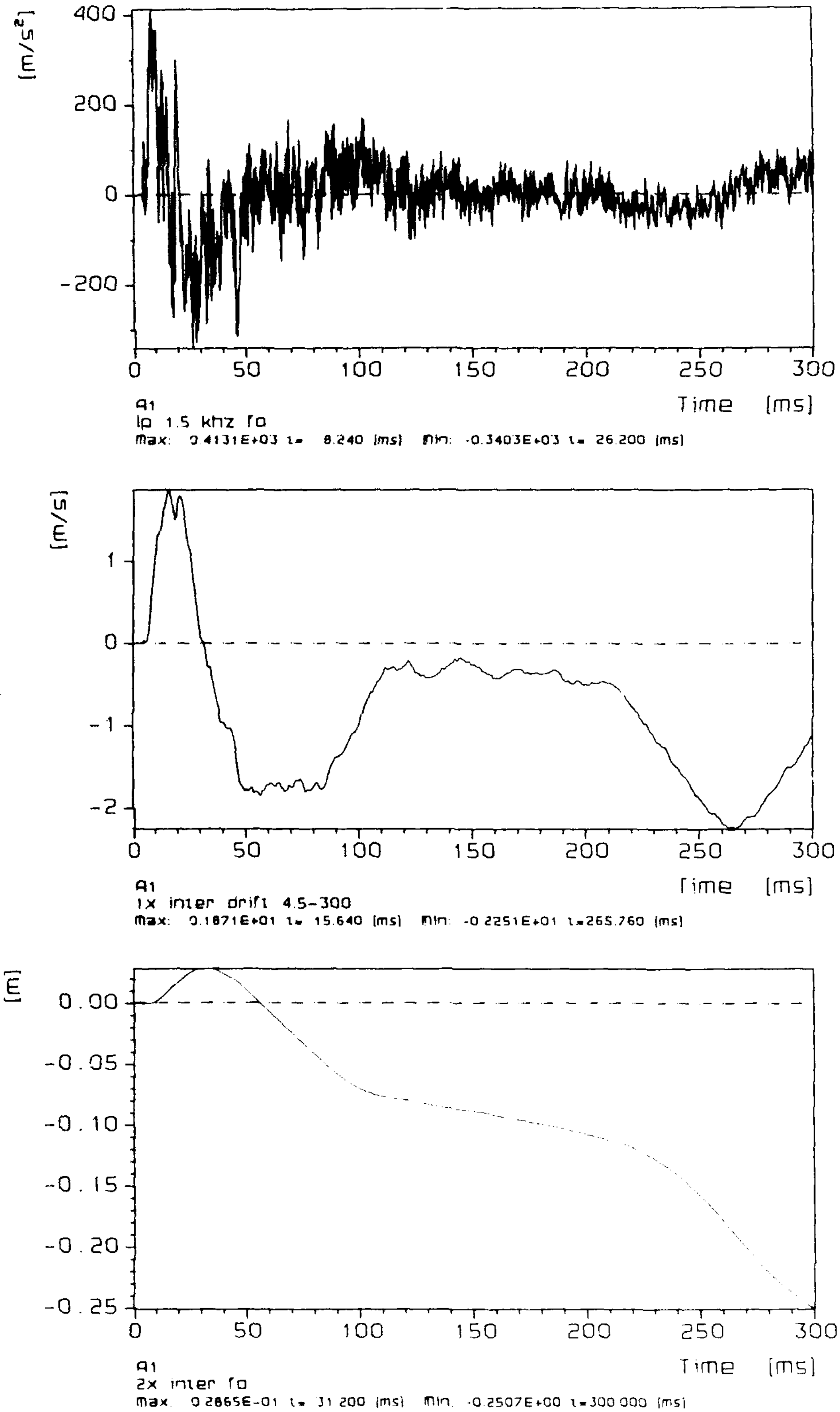
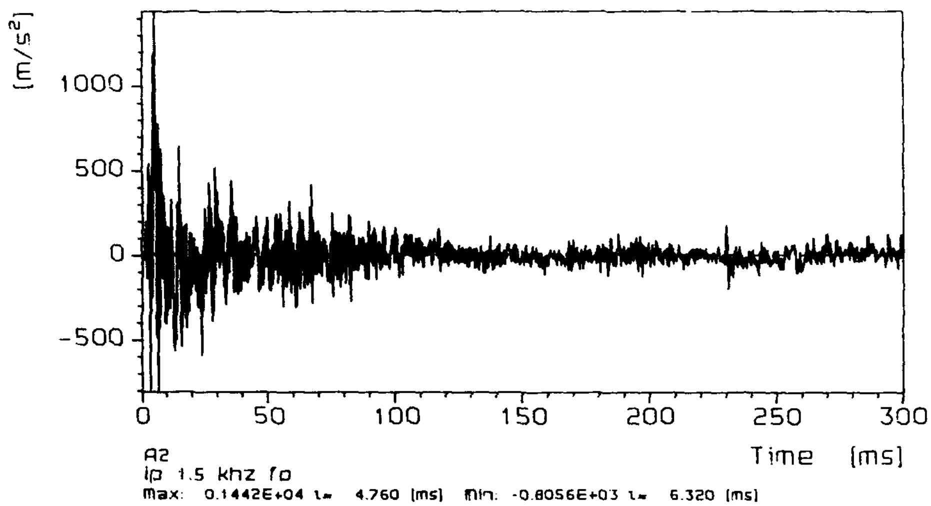
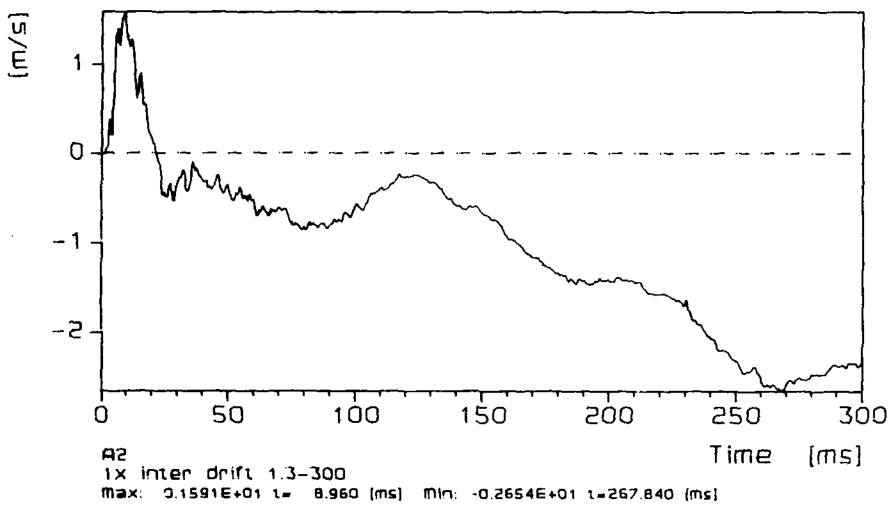


Figure 25 Accelerometer A1





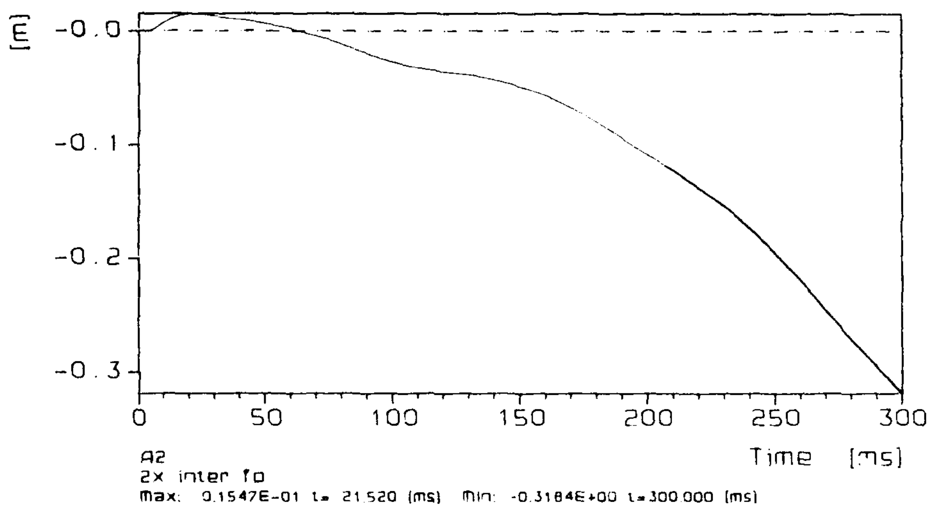


Figure 26 Accelerometer A2

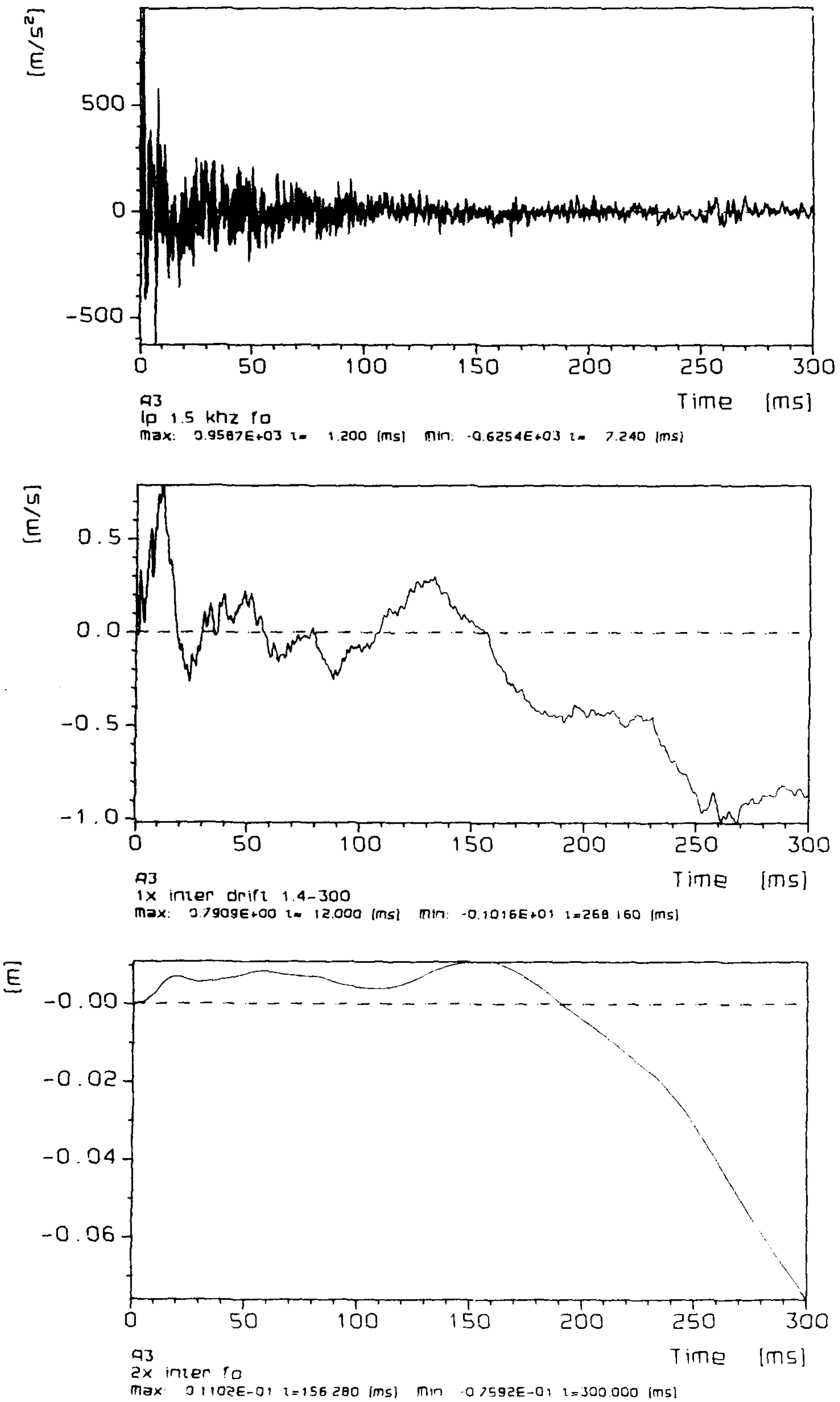


Figure 27 Accelerometer A3

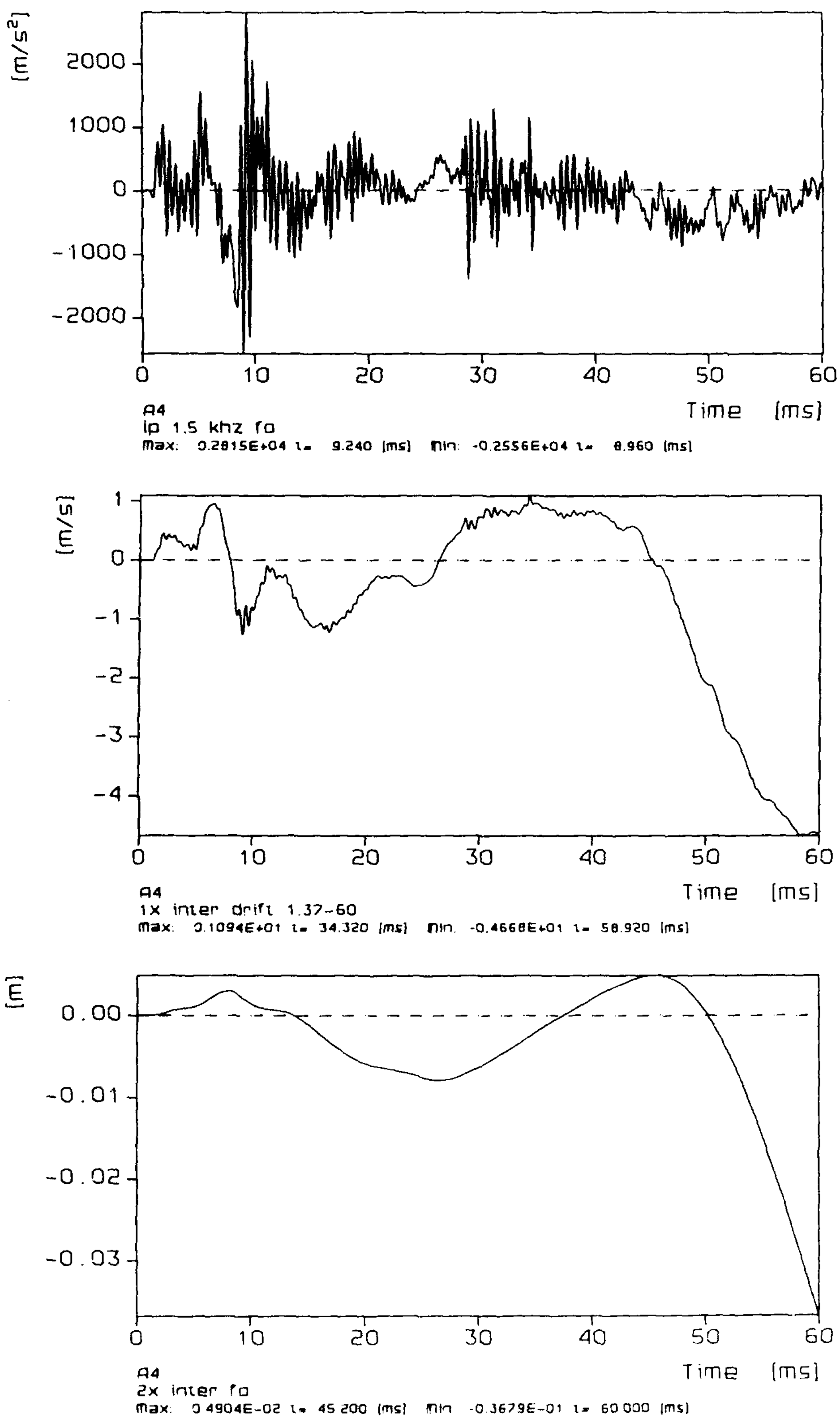
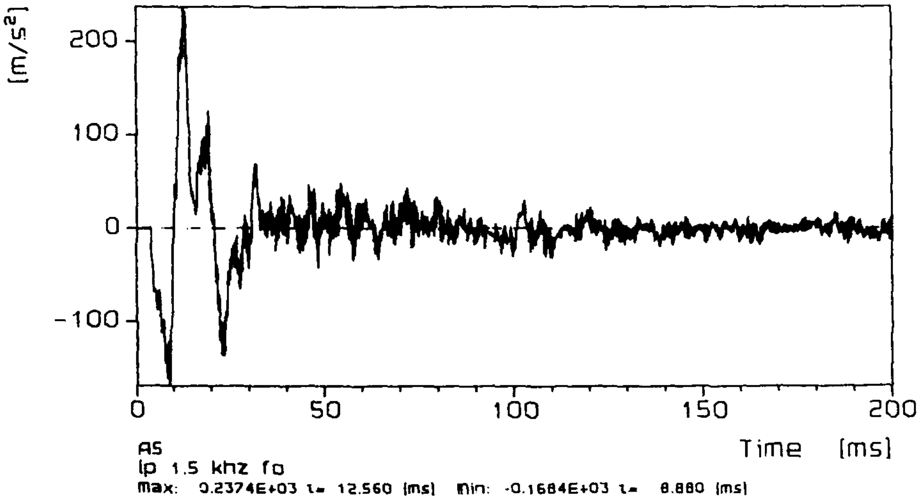
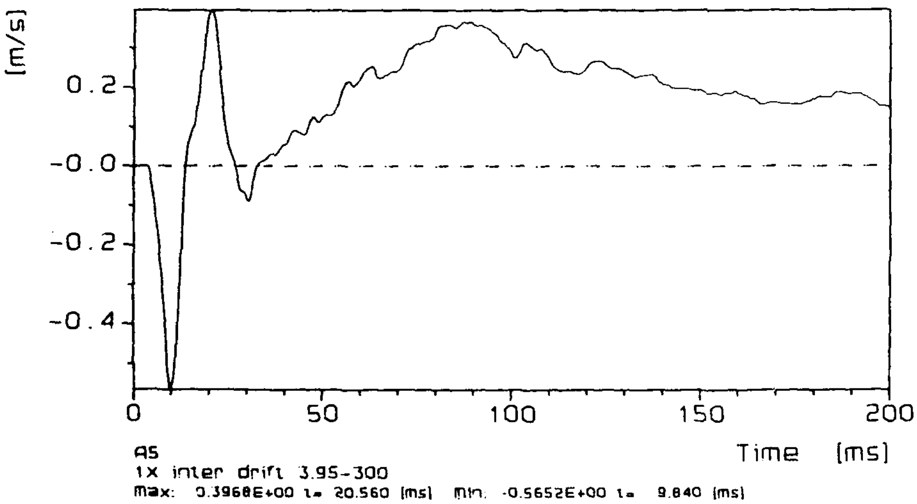


Figure 28 Accelerometer A4





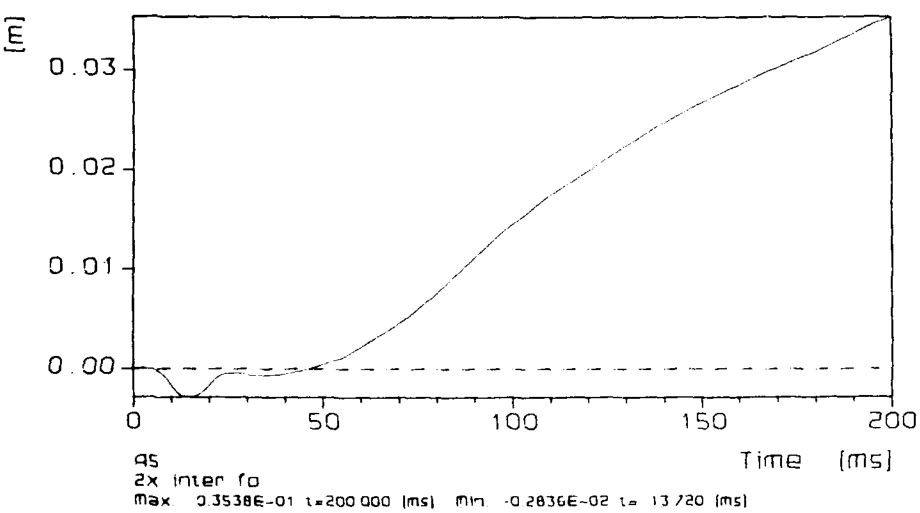


Figure 29 Accelerometer A5

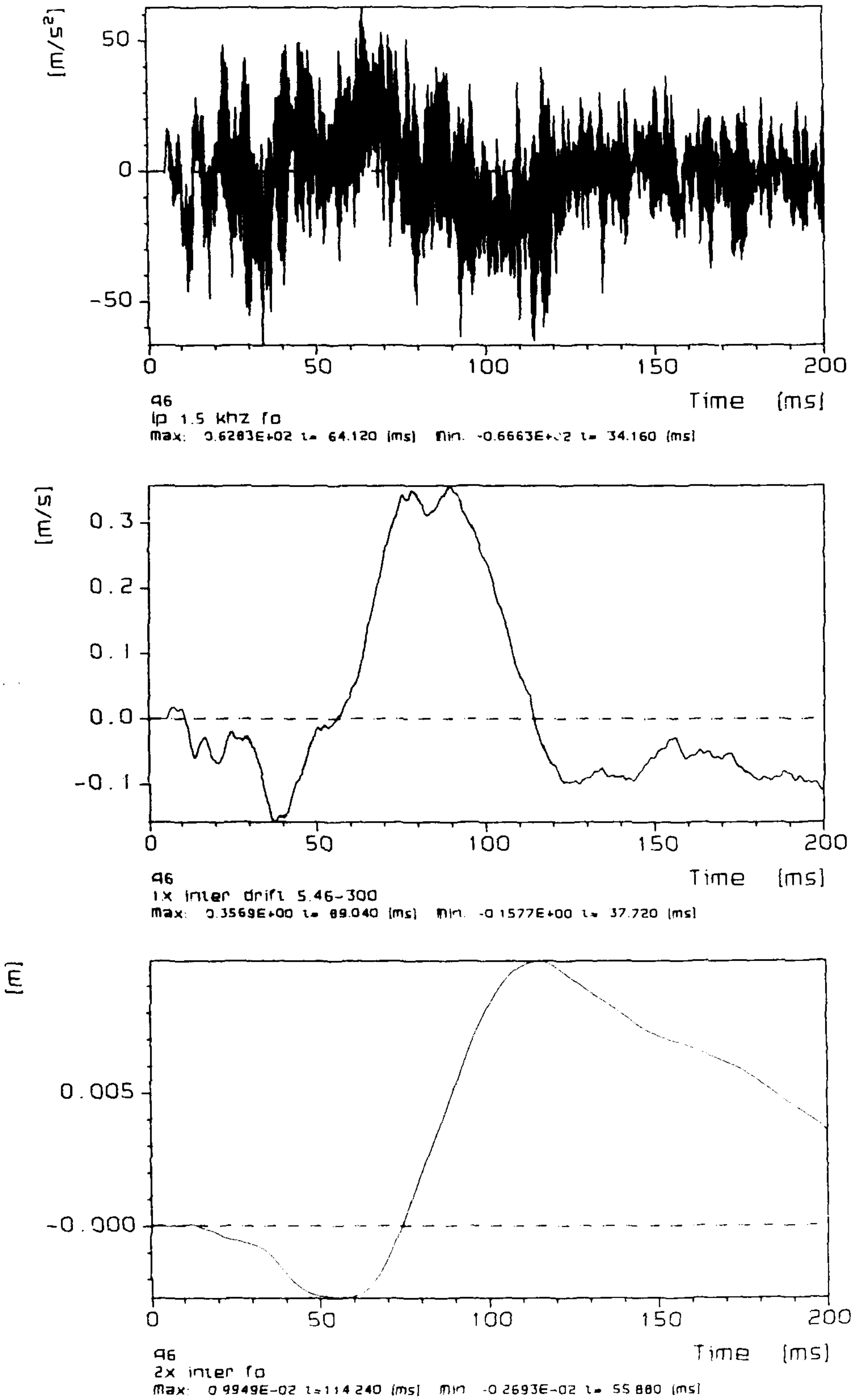


Figure 30 Accelerometer A6

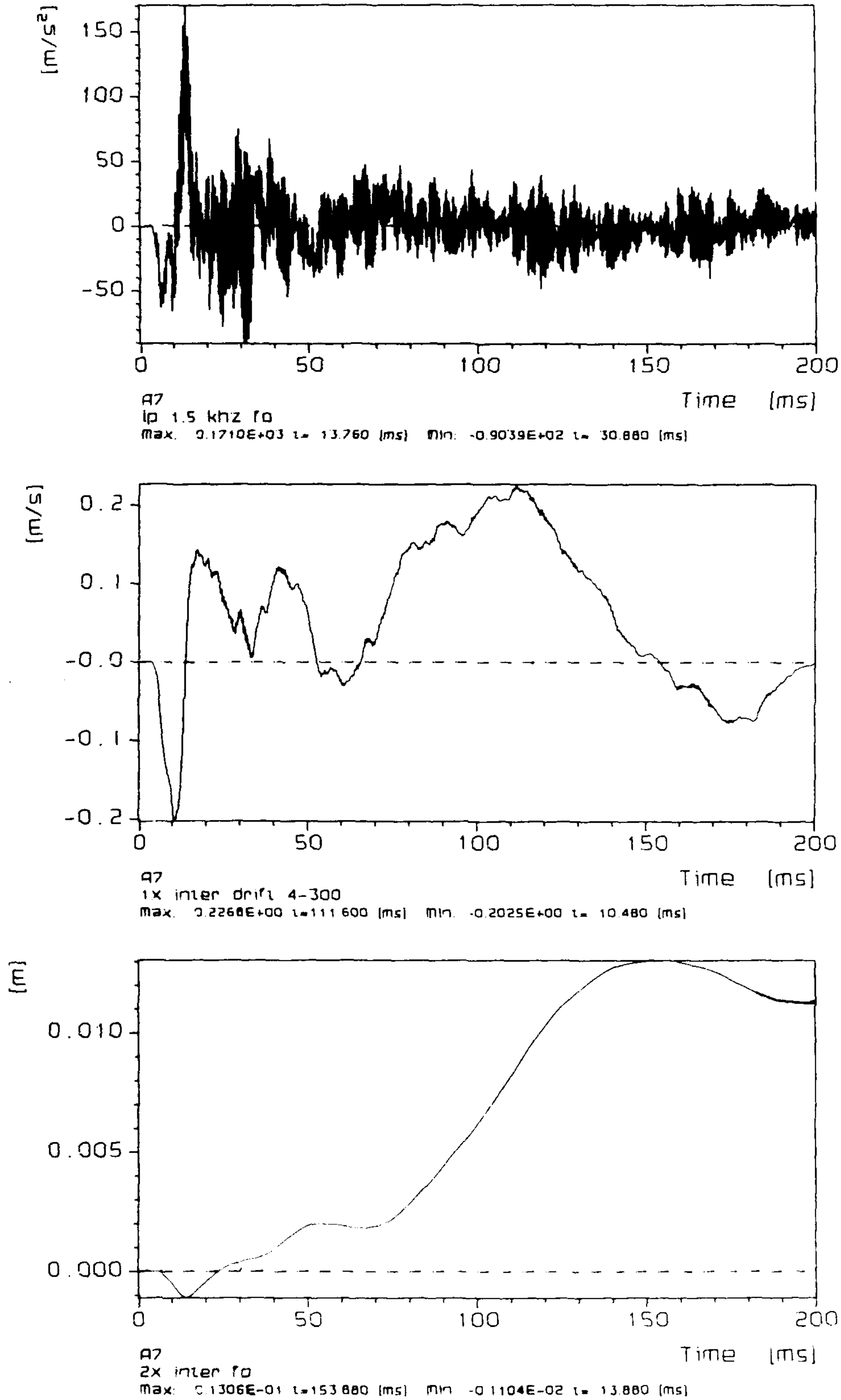
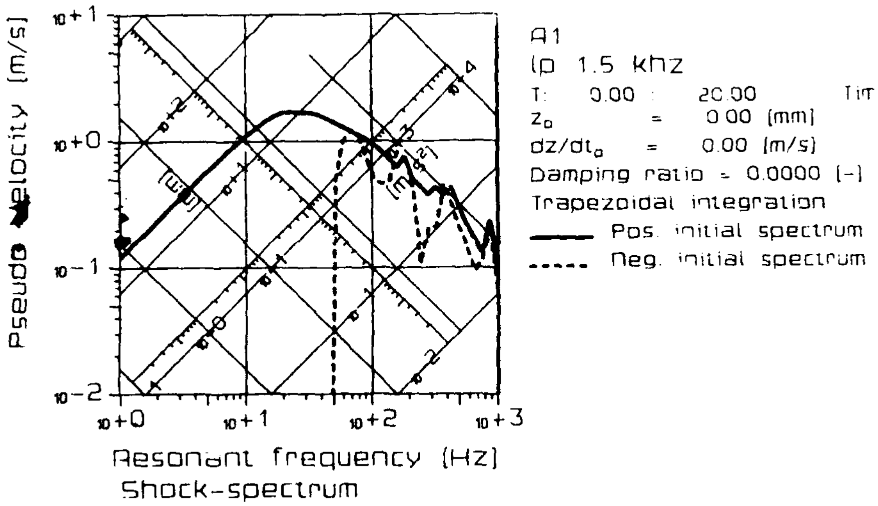
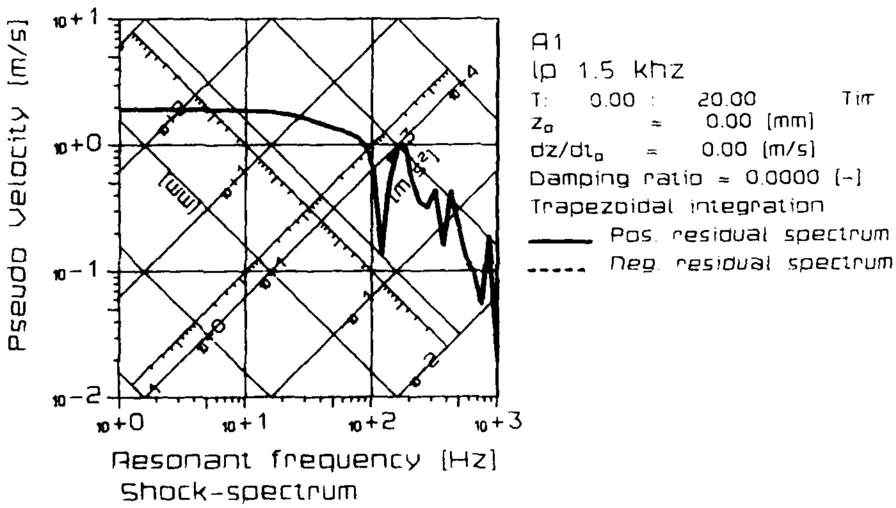


Figure 31 Accelerometer A7





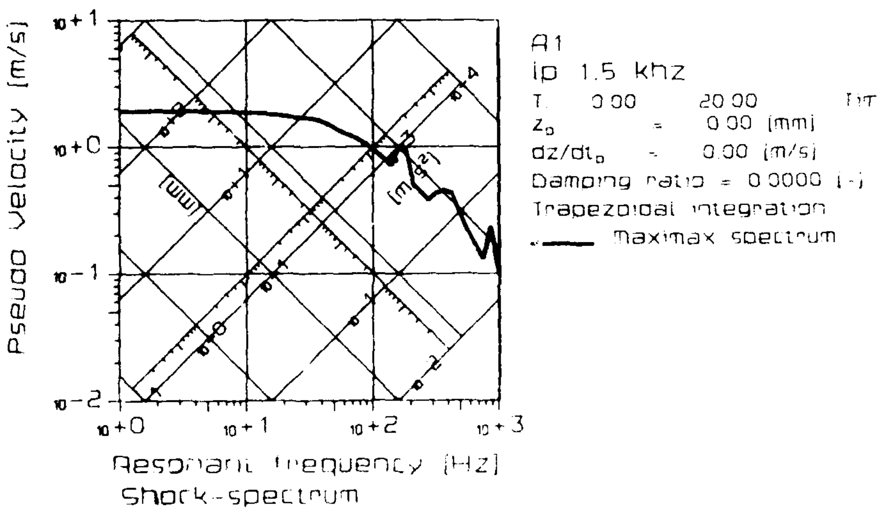
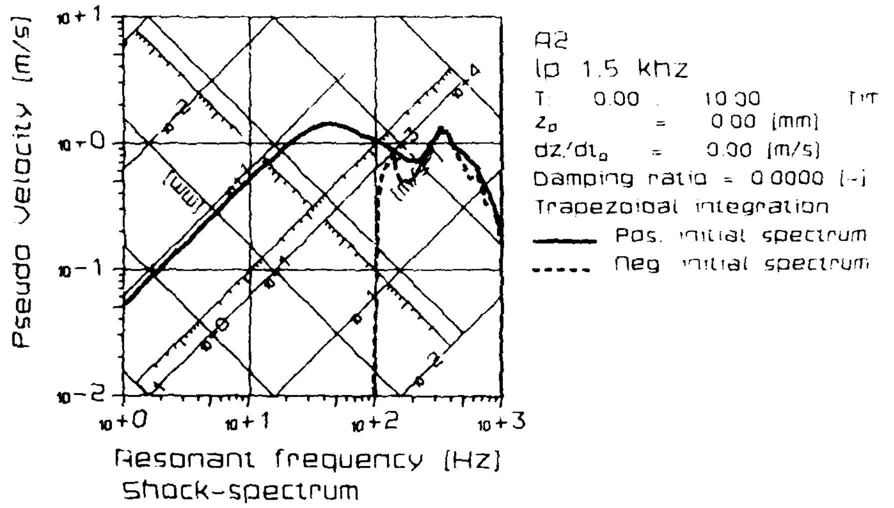
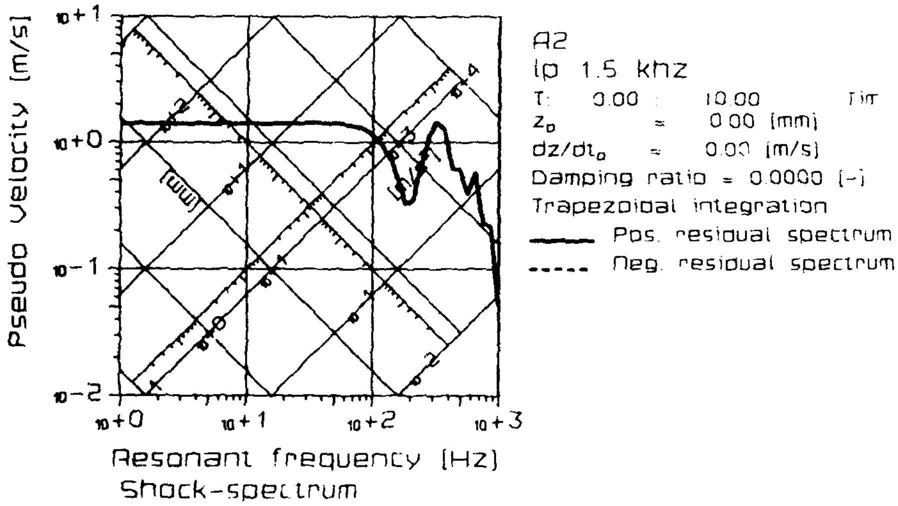


Figure 32 Undamped shock spectra of accelerometer A1





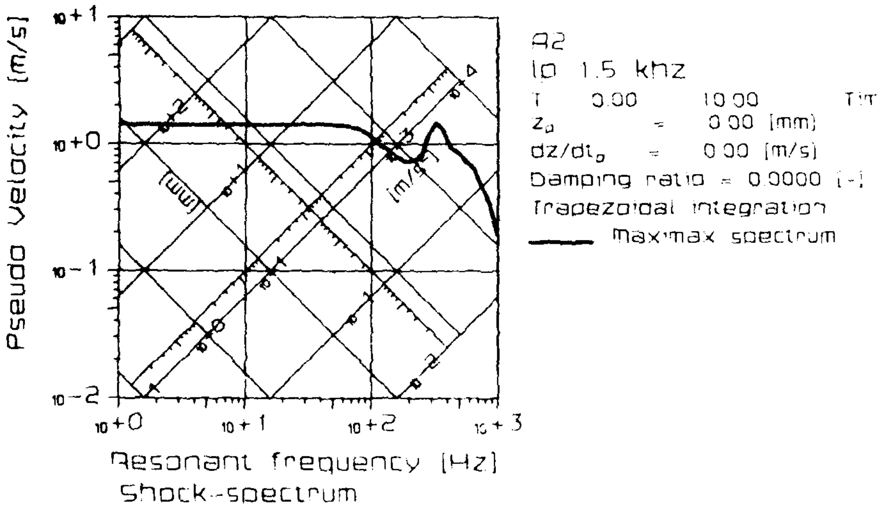
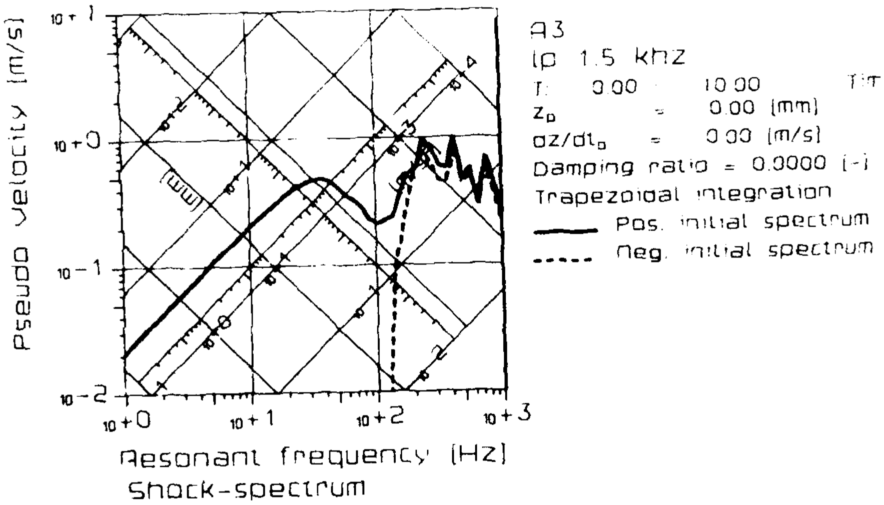
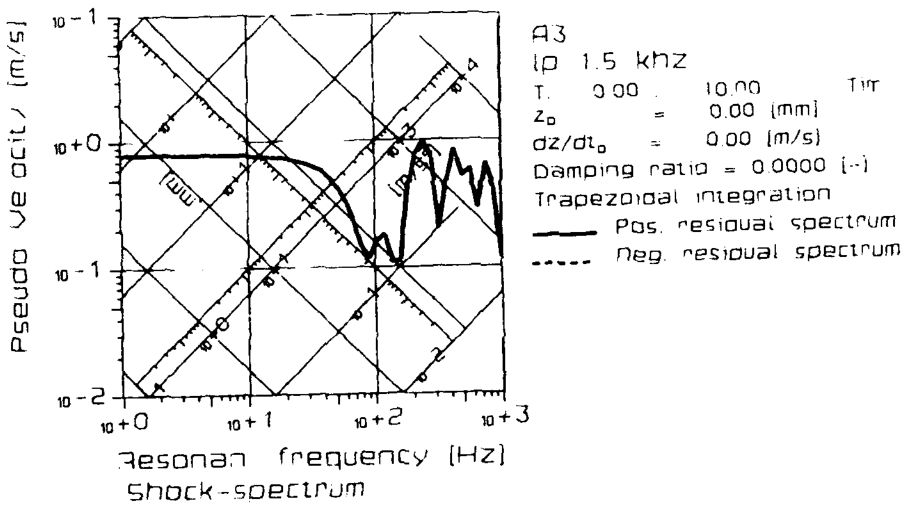


Figure 33 Undamped shock spectra of accelerometer A2





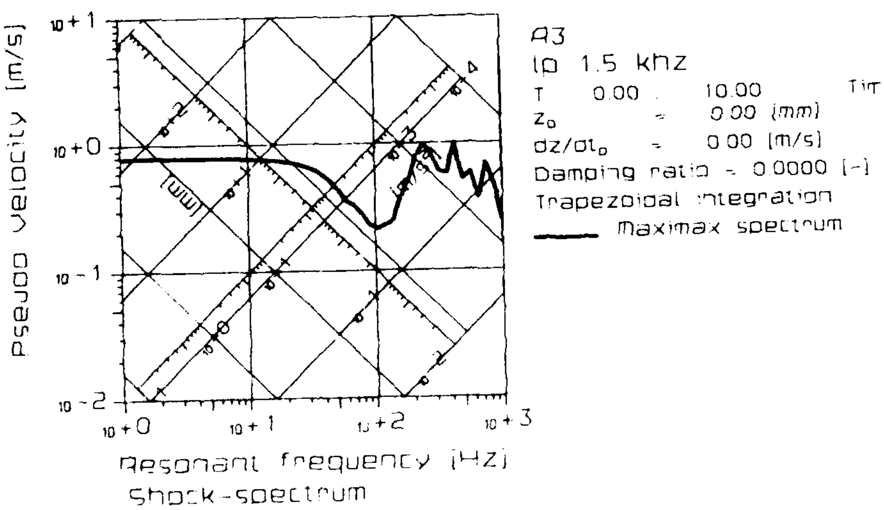


Figure 34 Undamped shock spectra of accelerometer A3

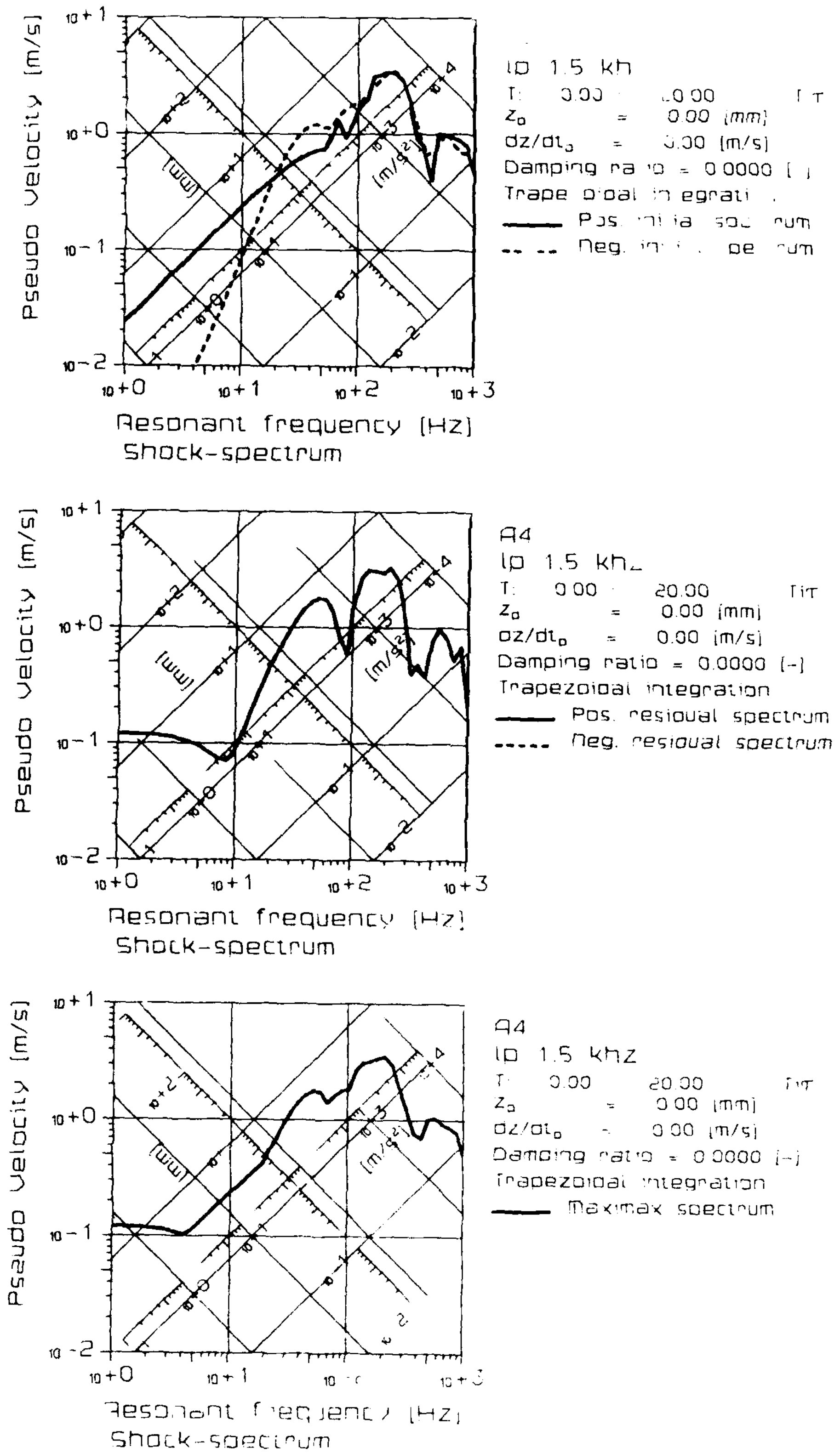
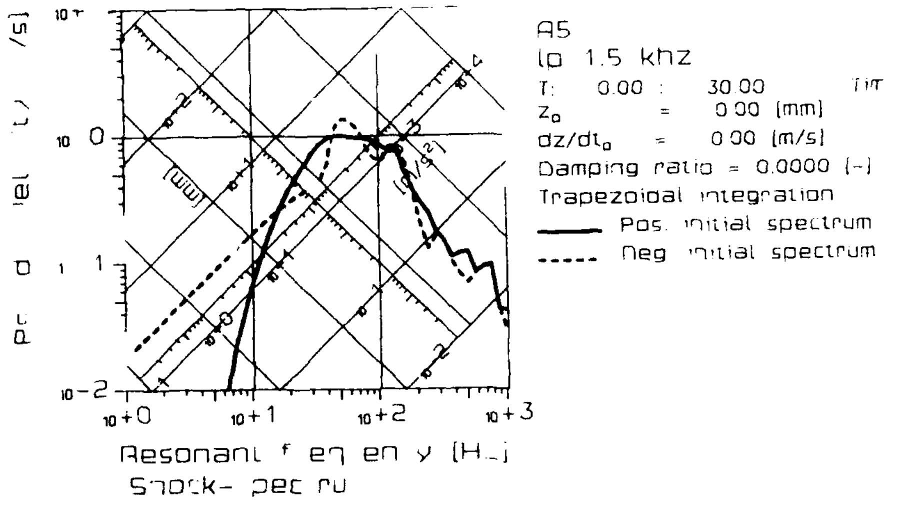
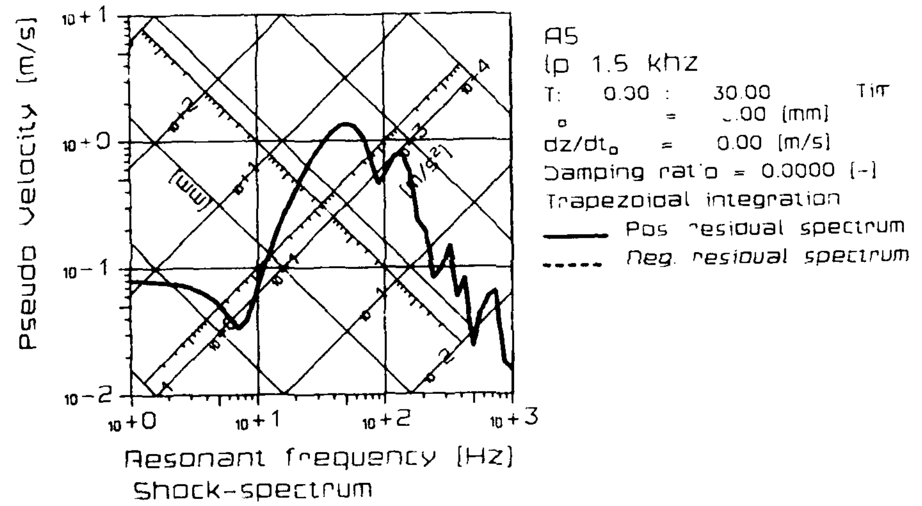


Figure 35 Undamped shock spectra of accelerometer A4





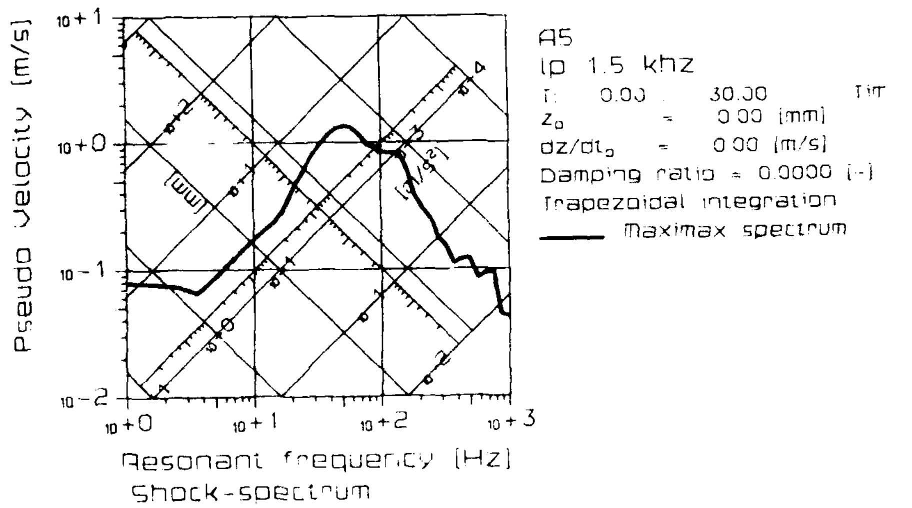


Figure 36 Undamped shock spectra of accelerometer A5

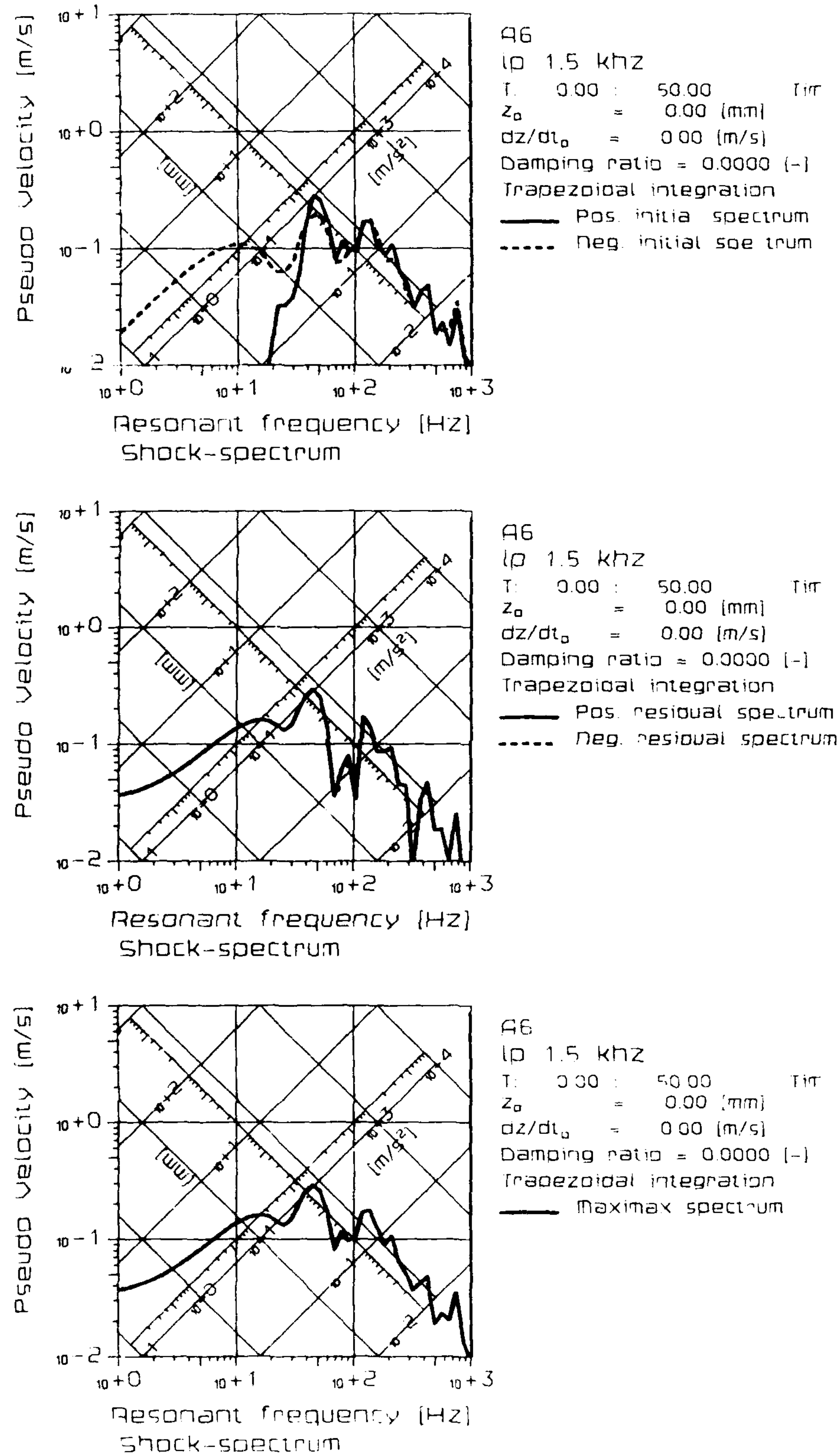


Figure 37 Undamped shock spectra of accelerometer A6

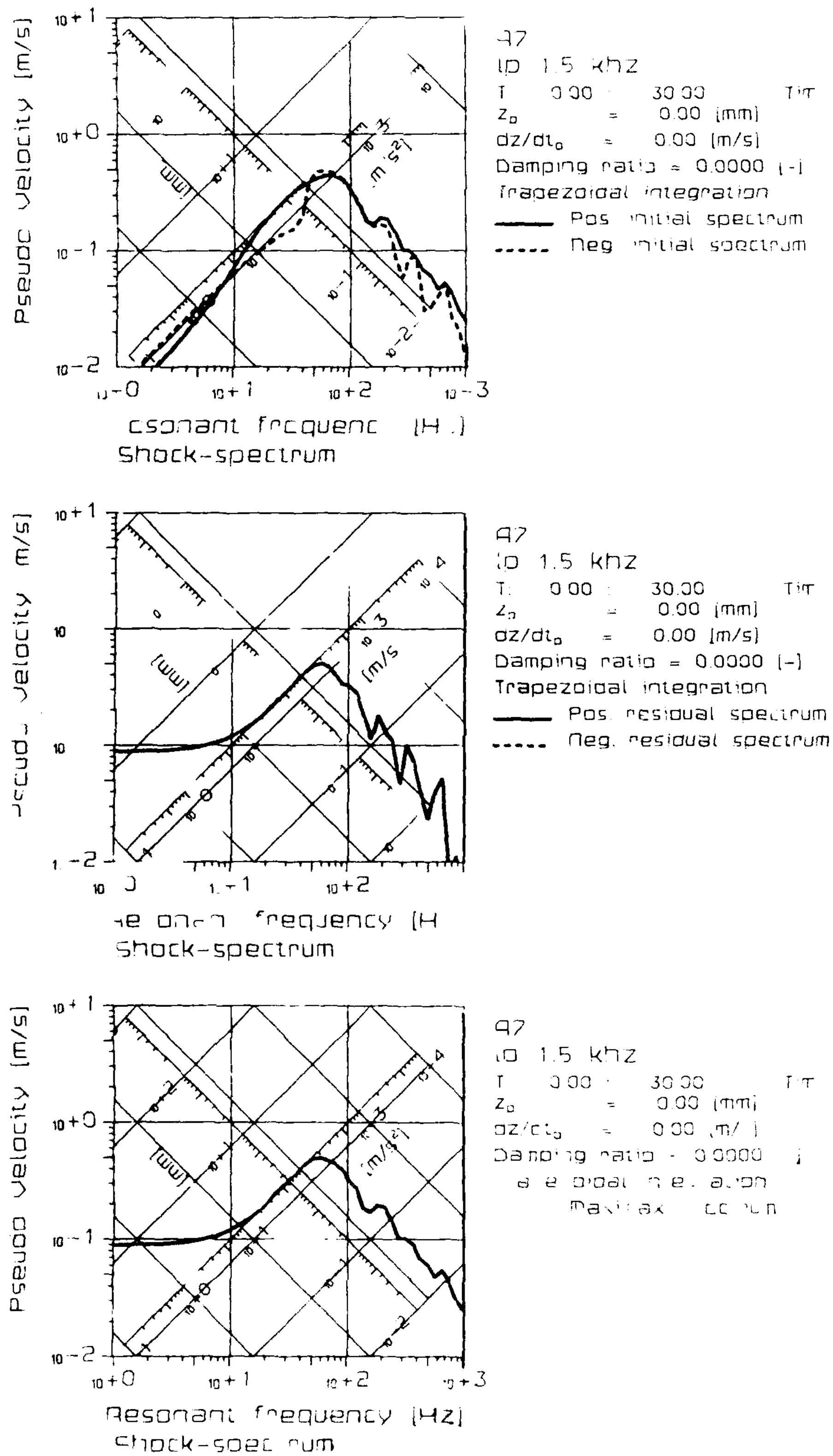


Figure 38 Undamped shock spectra of accelerometer A7

7 TEMPERATURE MEASUREMENTS

7.1 Position of the temperature transducers

During the experiment, three temperature measurements were performed. The location of the temperature measurements are summarized in Table 11 and are shown schematically in Figure 39.

Table 11 Position of the temperature transducers

Device	Height	Position
T1(1)	125 cm	beside Q1, SB, in experiment compartment
T2	118 cm	beside Q3, sleeping compartment
T3	149 cm	115 cm from CL, munition depository

(1) near venting hole

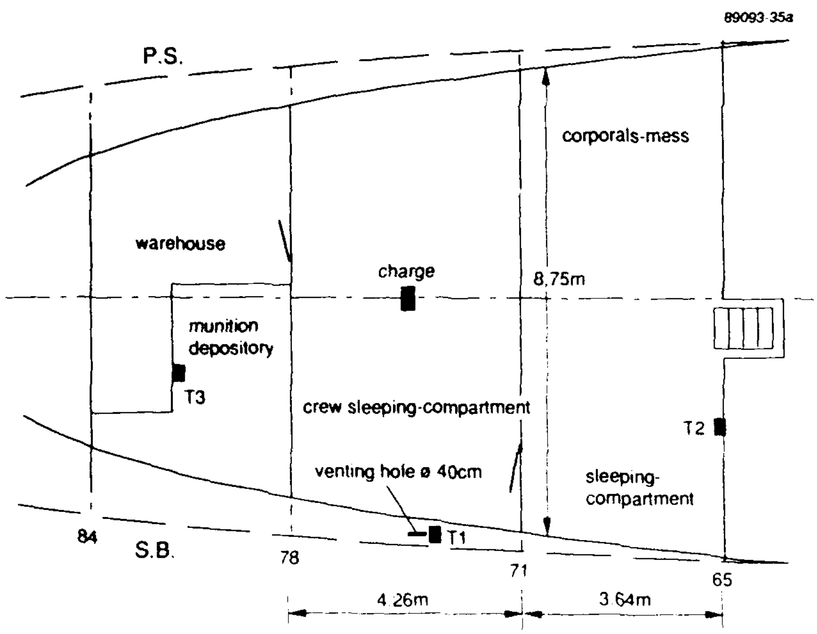


Figure 39 Schematic illustration of the positions of the temperature transducers

7.2 Discussion of the temperature measurements

In Figure 40, the recorded temperature increment T2 is shown, the contribution of T1 and T3 are omitted due to malfunctioning. In this figure, T=0 corresponds with the ambient temperature.

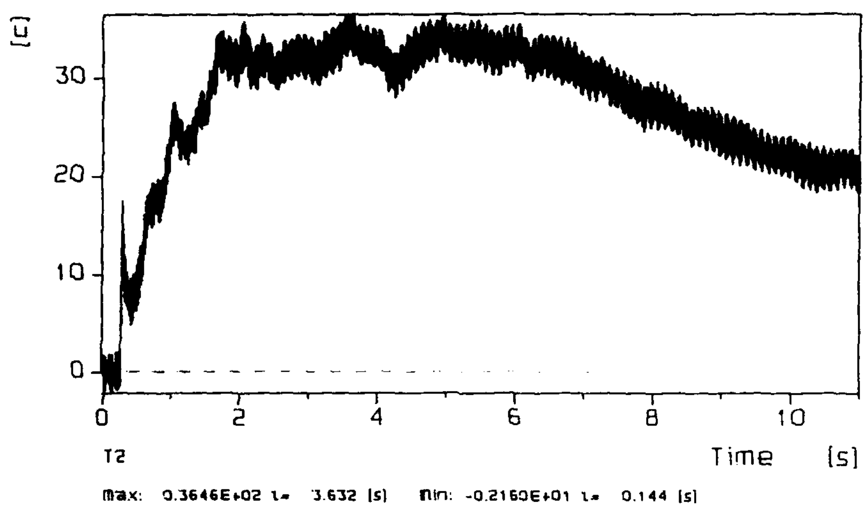


Figure 40 The temperature increment T2

8 BREAKWIRES

8.1 Position of the breakwires

In order to be able to determine the moment of collapse of the watertight doors, breakwires were used. The positions are summarized in Table 12 and shown schematically in Figures 41 and 42.

Table 12 Position of the breakwires

Device	Height[(1)]	Position
BW1	112 cm	back side of the door in BHD 71
BW2	27 cm	back side of the door in BHD 71
BW3	81 cm	back side of the door in BHD 78

(1) Height with respect to the lower side of the door

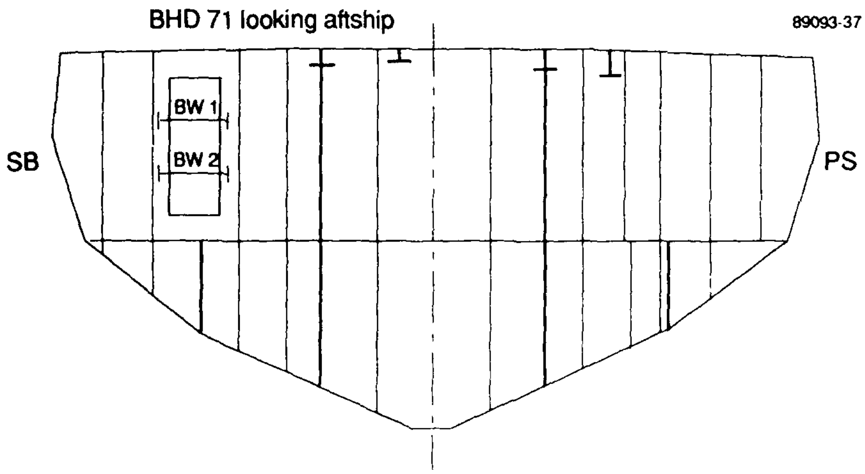


Figure 41 Schematic illustration of the positions of the breakwires in BHD 71

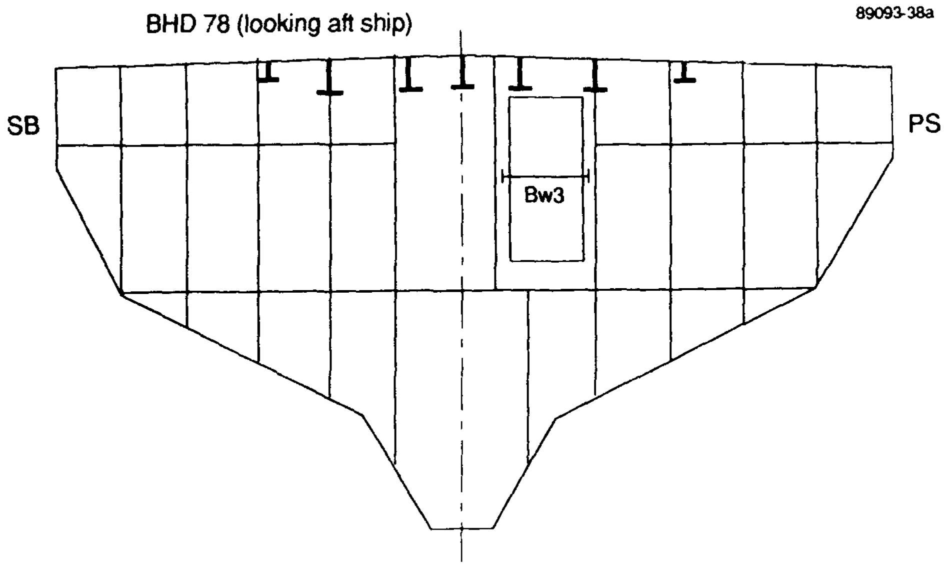


Figure 42 Schematic illustration of the positions of the breakwires in BHD 78

8.2 Discussion of the breakwire measurements

In Figure 43, the recorded signals are shown. It must be noted that the doors as well as BHD 71 and BHD 78 collapsed during this experiment.

From these signals a response time of 1.8 ms for BW1 and 1.6 ms for BW3 was found. The response time of BW2 is not so clear, perhaps 2.8 ms is a reasonable estimate. The response times can be compared with the arrival time of the shock front at the (symmetrically) placed blast transducers: BW1 and BW2 with B5 (2.8 ms), BW3 with B8 (1.3 ms). From this it appears that BW1 responded too soon, while the response time of the doubtful BW2 sensor seems to corresponds well. The response time of BW3 appears acceptable.

Comparing these times with the possible moment of collapse of BHD 71 and BHD 78 as determined from the quasi-static pressure measurements (± 10 ms) shows a considerable discrepancy.

This discrepancy and doubt suggests that the way the breakwires were mounted, and the microswitches used, were too sensitive to the twist of the door-frame and thus react on the shock in the bulkheads. The times determined are not the times that the doors collapsed, but probably the arrival time of the shock wave, as already indicated by the 2 and 5.5 kg TNT experiments.

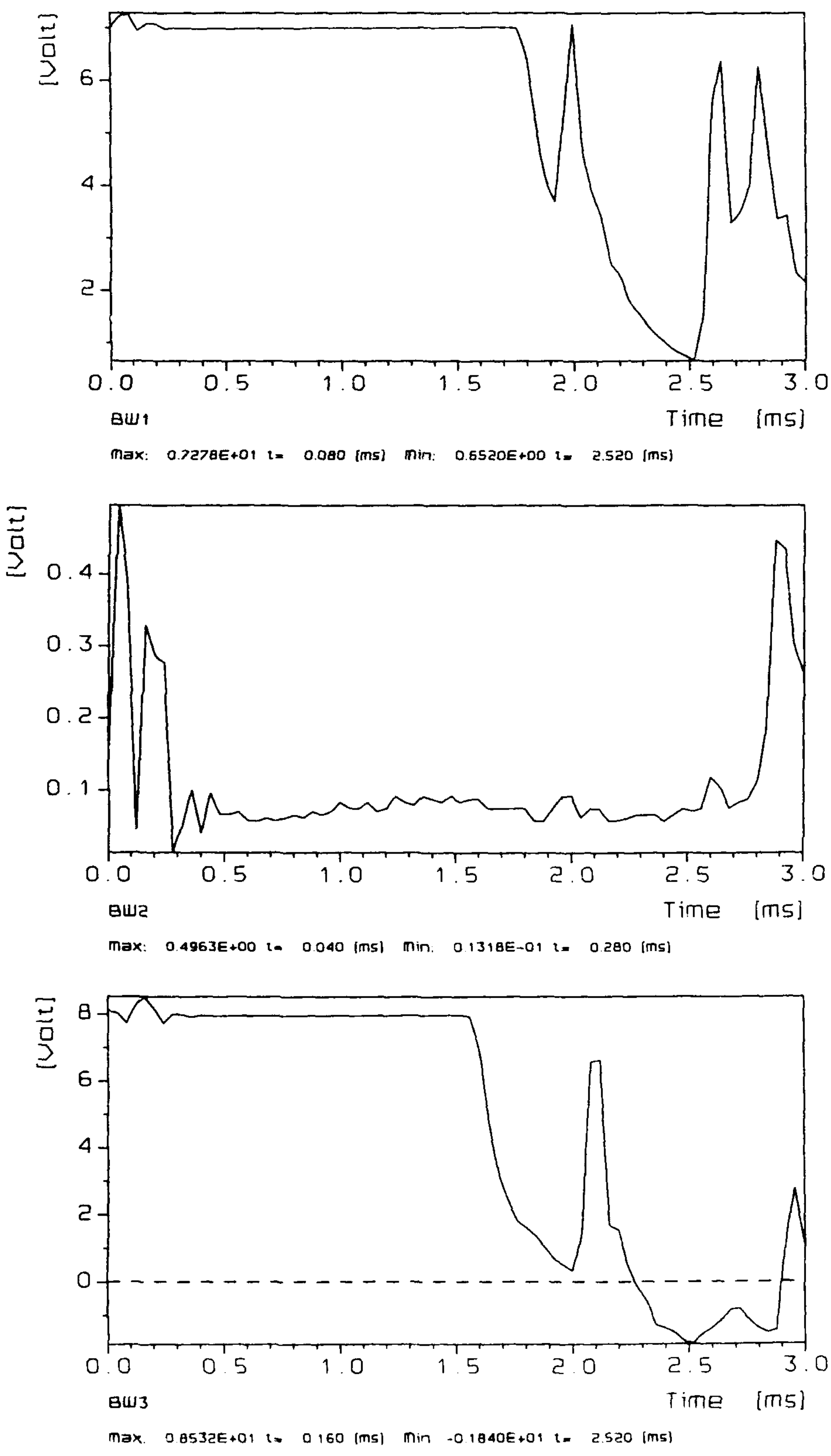


Figure 43 The breakwire signals

9 CONCLUSION

During the Wolf Phase II trial, a number of instrumented experiments in the crew forward and aft sleeping compartments were performed. During these experiments, attention was paid to blast, quasi-static pressure, strain, acceleration, temperature and the possible moment of collapse of the watertight doors, as well as rupture of structural elements.
Preceding the 15 kg TNT experiment, as reported in this paper, the instrumented 2 and 5.5 kg TNT experiments took place in the same compartment earlier that day. It is for this reason that there was no time for the technicians to replace damaged transducers or even repair malfunctioning transducers. The damage to the ship was not repaired either, only the upper deck was provisionally repaired. Although it is not within the scope of this report, it must be mentioned that the 15 kg TNT experiment resulted in severe damage to the experiment compartment as well as the adjacent compartments and the upper deck.

The blast measurements seem to be realistic, although transducer B1, in the experiment compartment in the vicinity of the venting hole, behaved rather strangely shortly after the arrival of the shock wave. The reason for this behaviour is not clear, it also happened during the 2 and 5.5 kg TNT experiments.
In contrast to the 2 and 5.5 kg TNT experiments, the theoretical predictions of peak pressure and arrival time (based on a centrally ignited, spherical charge) show a better correspondence with the experimental measurements.

The quasi-static pressure measurements seem to be realistic. From these measurements one can deduce that BHD 71 and BHD 78 collapsed ±10 ms after the ignition of the charge. The quasi-static pressure measurements in the experiment compartment, as well as in the adjacent compartments, are very similar after ±30 ms. The theoretical predictions of quasi-static peak pressure based on Baker and Weibull (for an enlarged compartment) correspond reasonably well with the recorded values after 30 ms. The rupture of BHD 78 resulted in the unexpected exposure of transducer Q7 (mounted in the warehouse) and, thus, overload.

The strain gauges fixed opposite each other were depicted in one figure. A number of strain gauges were already damaged due to the 2 and 5.5 kg TNT experiments earlier that day. Due to the extreme conditions of this experiment, a number of the remaining strain gauges functioned only for a short time. Nevertheless, the recordings seem to be reliable. The response of the strain gauge

couple glued on the watertight door in BHD 71 corresponds remarkably well with the conclusions drawn from the quasi-static pressure recordings concerning the collapsing of the bulkheads.

The acceleration was measured at seven locations. The velocity and displacement were also determined by integrating these recordings. However, a number of ad hoc digital signal analysis techniques were used, which may have had a large influence on these integrated signals. The undamped shock spectra of the acceleration recordings are also included.

Two temperature transducers malfunctioned during this experiment; only one transducer registered a reliable signal.

The watertight doors, as well as the bulkheads (BHD 71 and 78), collapsed during this experiment. The possible moment of collapse deduced from the breakwire measurements seems to be unrealistic, compared with the time deduced from the quasi-static pressure and strain measurements. It must be concluded that these times correspond better with the arrival times of the shockwave. From this it must be concluded that the breakwire set-up used is too sensitive to shock, as already indicated by the 2 and 5.5 kg TNT experiments.

From the recordings presented in this report, it may be concluded that the instrumented 15 kg TNT experiment has resulted in a valuable set of data which can be used to validate the prediction models.
Notwithstanding the violence and demolishing processes during these kind of destructive experiments, the recordings are of good quality due to the special preparations, mounting and protection methods applied.

10 AUTHENTICATION

The realization of the Wolf Phase II trial as presented in this set of reports was achieved due to the effort of a number of people from the Explosion Prevention Group: the technicians, Mr. M.W.L. Dirkse, Mr. Ph. van Dongen, Mr. R.M. van de Kasteele and Mr. A.M. Steenweg, who carried out the experiments and processed the results.
We would also like to acknowledge the supporting services of the Royal Netherlands Navy.

Date:

14 apr. 1992

J. Weerheijm
(Project Manager)

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(Author)

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Wolf II: Measurement results of the 3 kg TNT experiment in the crew front sleeping compartment
PML - TNO, 1992-11

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Instrumented experiments aboard the frigate "WOLF"
Wolf II: Measurement results of the 5.5 kg TNT experiment in the crew aft sleeping compartment
PML - TNO, 1992-12

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Wolf II: Measurement results of the 12 kg TNT experiment in the crew front sleeping compartment
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Verhagen, Th.L.A.; Kasteele, R.M. van de
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Wolf II: Measurement results of the 15 kg TNT experiment in the crew aft sleeping compartment
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PML-TNO, 1990-31

Erkel, A.G. van
Roofdier internal blast damage
Part I: Bare charge experiments in the aft sleeping compartment
PML-TNO, 1992-(to be published)

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Part II: Bare charge experiments in the front sleeping compartment
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Part III: Experiments with shells and asymetrical located bare charges
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Instrumented experiments aboard the frigate "WOLF". Wolf II: Measurement results of the 15 kg TNT experiment in the crew aft sleeping compartment.
(Geïnstrumenteerde beproevingen aan boord van het fregat "WOLF". Wolf II:Meetresultaten van de 15 kg TNT beproeving van het manschappen slaapcompartiment op het achterschip .)

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).

In this report recordings of an instrumented experiment in the crew aft sleeping compartment are presented.

During this experiment, a non-fragmenting charge of 15 kg TNT was initiated.

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